Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Agronomic Performance of Acaí (Euterpe oleracea) Using Organic Compost Associated with Dolomitic Limestone

Valdeci Junior Fonseca Pinheiro
valdecijr04091997@usp.br

USP: Universidade de Sao Paulo https://orcid.org/0000-0002-7190-8265

Antônia Benedita da Silva Bronze
Jessivaldo Rodrigues Galvão
Layse Barreto Almeida

Research Article

Keywords: composting, corrective Practice, fruit growing, mineral Nutrition

Posted Date: November 14th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-7861373/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Agronomic Performance of Acaí (*Euterpe oleracea*) Using Organic Compost Associated with Dolomitic Limestone

AUTHORS:

1- Valdeci Junior Fonseca Pinheiro*,

2- Antônia Benedita da Silva Bronze,

3- Jessivaldo Rodrigues Galvão,

4- Layse Barreto de Almeida,

AFFILIATIONS:

1- University of São Paulo, "Luiz de Queiroz" College of Agriculture, Department of Soil Science, Piracicaba, São Paulo, Brazil, https://orcid.org/0000-0002-7190-8265

2- Federal Rural University of the Amazon, Institute of Agricultural Sciences, Belém, Pará, Brazil, https://orcid.org/0000-0003-1452-2486

3- Federal Rural University of the Amazon, Institute of Agricultural Sciences, Belém, Pará, Brazil, https://orcid.org/0000-0001-6454-7556

4- Federal Rural University of the Amazon, Institute of Agricultural Sciences, Belém, Pará, Brazil, https://orcid.org/0000-0003-4996-3345

CORRESPONDING AUTHOR:
Valdeci Junior Fonseca Pinheiro
University of São Paulo, "Luiz de Queiroz" College of Agriculture
Department of Soil Science
Av. Pádua Dias, 11, Piracicaba, São Paulo, Brazil, 13418-900
E-mail: valdecijr04091997@usp.br

OTHER AUTHORS' EMAILS:
Antônia Benedita da Silva Bronze: antonia.silva@ufra.edu.br
Jessivaldo Rodrigues Galvão: jessigalvao50@gmail.com
Layse Barreto de Almeida: almeidablayse@gmail.com

Data availability: All relevant data is in the article.	
Conflict of interest: The authors declare that there is no conflict of interest.	
Citation of data: Citations of data from another research are duly referenced in the article.	

Authors' contribution

Valdeci Junior Fonseca Pinheiro: study conception, experimental design, experiment conduction, statistical data analysis, and full manuscript writing.
Antônia Benedita da Silva Bronze: critical revision of the manuscript and contribution to the interpretation of the results.
Jessivaldo Rodrigues Galvão: critical revision of the manuscript and text editing.
Layse Barreto de Almeida: experimental design and manuscript revision.

ABSTRACT

Objectives: This study aimed to evaluate the effect of compost doses associated with dolomitic limestone on the biometry, nutritional, and physiological state of Euterpe oleracea under organic cultivation, contributing to sustainability in the Amazon.

Methods: The experiment was conducted in Santo Antônio do Tauá/PA, in the community of Campo Limpo, using a randomized block design in a 7 × 2 factorial scheme. Factor 1 comprised six compost doses (2, 4, 6, 8, 10, and 12 kg) and factor 2 included the presence or absence of liming. The control received no fertilization. In total, 14 treatments with six replicates resulted in 84 experimental units, each containing two BRS Pai d'égua Euterpe oleracea plants. Biometric, nutritional, and physiological variables were evaluated.

Results: Compost application, particularly at 8–10 kg combined with liming, provided the best results. Organic fertilization increased stipe height by 41.66%, circumference by 29.71%, circumference at breast height by 16.13%, and number of leaves by 11.01%. It improved nutrient levels (N > S > Ca > K > P > Mg; B > Mn > Fe), enhanced relative chlorophyll content by 38.84%, and positively affected CO_2 assimilation, stomatal conductance, transpiration, intercellular CO_2 concentration, and water use efficiency.

Conclusions: The combination of 8–10 kg of compost per plant with dolomitic limestone promotes better biometric, nutritional, and physiological performance of Euterpe oleracea under organic management, supporting sustainable açaí production in the Amazon.

Keywords: composting; corrective Practice; fruit growing; mineral Nutrition.

Introduction

Euterpe oleracea Mart. Arecaceae, commonly known as the *Euterpe oleracea* plants, is a fruit tree native to the Amazon. It is naturally found in northern Brazil, particularly in the states of Pará, Amazonas, and Amapá. Its economic importance is primarily derived from the commercial production of its pulp and fruit (Sena et al., 2022). Recently, there has been significant demand for products derived from this productive and essential Amazonian palm, which is among the most prominent species of *Euterpe Mart*. in Brazil (Bezerra et al., 2018; Ximenes et al., 2020).

Brazil is the world's largest producer of açaí, generating millions of US dollars in revenue from this fruit. The state of Pará, located in the northern region of the country, is a prominent player in açaí production, both nationally and globally. This prominence is largely attributed to the traditional extractive practices employed by the local Amazonian population, which have significantly contributed to the state's leading position in the açaí market (Figueiredo et al., 2022; Matta et al., 2020; Silva et al., 2017; Tavares et al., 2022; Tavares, 2017). The potential production and consumption of the fruit of this crop between 2015 and

2021 have increased significantly, exceeding 1,400,000 tons in 2021 (EMBRAPA, 2023). This market demand, driven by its high nutritional value, antioxidant and medicinal properties, has led to the consumption of açaí in Brazil's main capitals and exports to mainland Europe and countries such as the United States, Australia, Japan and China (Barros et al., 2022; Silva et al., 2023).

This palm naturally thrives in “várzea” and “igapó” ecosystems, which are ecosystems with hydromorphic soils in flat, low areas bordering rivers, and with proper management, its fruit production can reach approximately 9 tons per hectare. However, the growing national and international demand for açaí juice has driven an expansion of its cultivation in irrigated areas (Lindolfo et al., 2020; Oliveira et al., 2002, 2017). The domestication of the species, such as the BRS-Pará and BRS-Pai d'égua cultivars, which are adapted to “terra firme” conditions (in irrigated areas), has facilitated its cultivation in extensive areas (Farias Neto, 2019; Homma et al., 2006).

In the Amazon, soils are naturally diverse, with 70% latosols and argissols (oxisols and ultisols, respectively, according to the US soil classification), and a limited presence of other types (Quesada et al., 2011). The main physiographic environments are “terra firme” (80%), “várzea,” and “igapós” (Inceptisols or Entisols, according to the US soil classification), with terra firme soils having low natural fertility, low cationic capacity (CTC), and acid pH (Lima et al., 2006; Moreira & Fageria, 2009). Correcting soil acidity is essential to promote plant growth, as this practice increases pH, provides essential nutrients such as Ca^{2+} and Mg^{2+}, reduces Mn^{2+} and Al^{3+} toxicity, improves nutrient absorption by plants and results in higher crop yields (Campos et al., 2022; Hartemink & Barrow, 2023; Jiang et al., 2018; Silveira et al., 2021; Vazquez et al., 2019; Zhang et al., 2020).

The challenges for the future in terms of food production are causing concern, especially as the population increases (Lal, 2020; Myers et al., 2017). For this reason, satisfactory agricultural performance is indispensable today (improving soil fertility and maintaining crop productivity) to guarantee societies' food security (Bai et al., 2018; Bokor et al., 2021; Lal, 2020). However, the intensive use of mineral fertilization in the long term can lead to environmental pollution and soil degradation, and have a negative impact on the sustainable production of açaí fruits in “terra firme” areas (Campbell et al., 2018; Hossain et al., 2022).

In this context, organic fertilization provides organic matter, which is a 'reservoir of nutrients,' supplying these essential elements for plant growth and development, improving physical properties, promoting microbial activity and soil metabolism (Brichi et al., 2023; Deng, 2017; Han et al., 2022; Wu et al., 2021) and ultimately enhancing soil health in Brazilian tropical conditions (Cherubin et al., 2025). In summary, organic farming makes it possible to improve soil fertility by using organic compost as a way of fertilizing it, since the increase in nutrient levels in the soil depends on the characteristics and quantity of organic waste added to it (Al-Suhaibani et al., 2020; Yang et al., 2019; Yu et al., 201a9)

Currently, agricultural production faces problems related to the growing amount of waste produced by various activities (Dussadee & Ramaraj, 2023). Many of these residues are discarded in the agricultural process, such as agricultural crops, animal manure, agro-industrial by-products and other organic compounds (Dussadee & Ramaraj, 2023; Manmai et al., 2021; Obey et al., 2022). As part of the bioeconomy, the circular economy aims to understand how to reduce the mass of this waste (Santana, 2020), associated with sustainability, which comprises the ideal balance between economic, social and environmental aspects (Parada et al., 2017).

In this context, the hypothesis (the proper management of organic fertilization promotes gains in growth, nutritional and physiological) underlying this research is based on the lack of information regarding agronomic responses in the management and nutritional diagnosis of fruit trees, such as the açaí palm (Ribeiro et al., 2020), through organic fertilization. Previous studies have highlighted organic matter as a key alternative for enhancing soil structure, water retention capacity, and physical and biological properties (Adetunji et al., 2020; Dawson & Smith, 2007). Therefore, this study aimed to evaluate the effect of compost doses combined with dolomitic limestone on the biometry, nutritional status, and physiological condition of açaí plants under organic cultivation, contributing to sustainable production in the Amazon.

Materials and Methods

Characterization of the Study Area

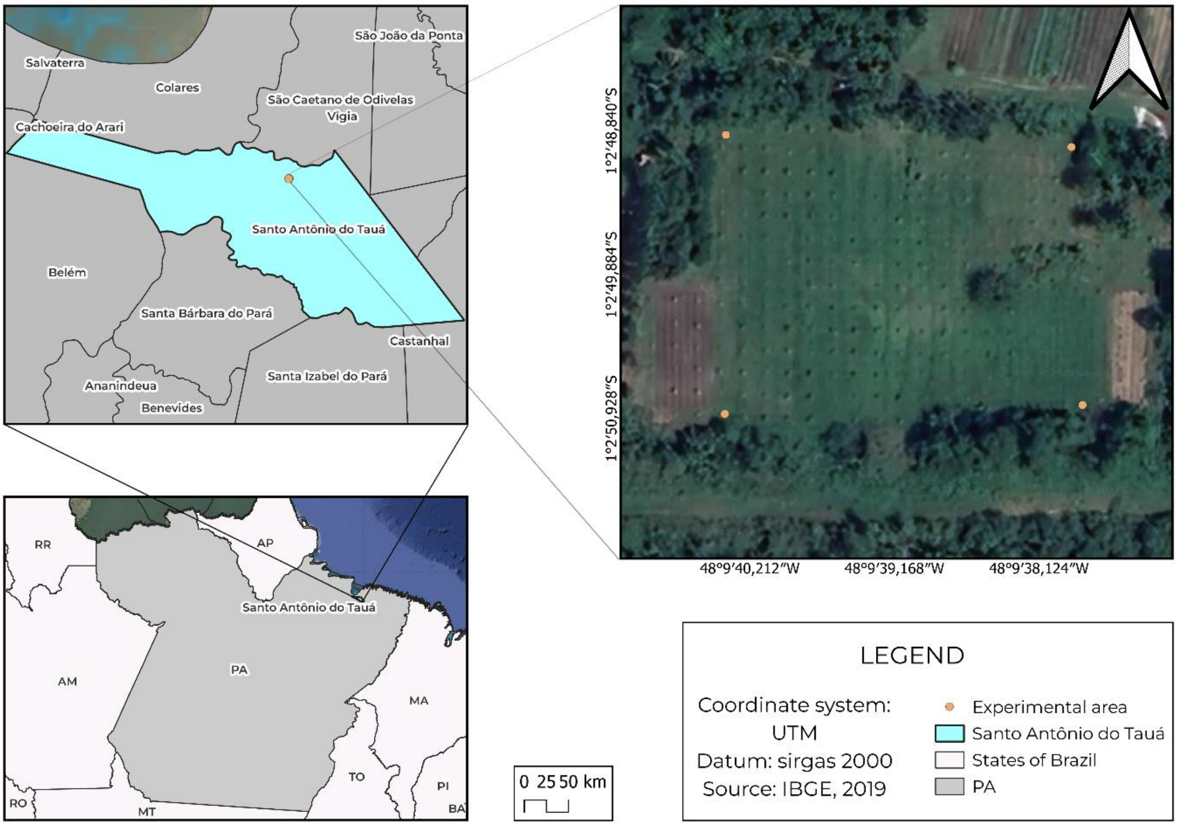
The study area is located in the municipality of Santo Antônio do Tauá, Pará (1°9′7″ S, 48°7′44″ W), approximately 63.2 km from Belém/PA, in the community of Campo Limpo. This community is represented by the Rural Producers Association of Campo Limpo (APROCAMP) (1°2′ S, 48°10′ W) (IBGE, 2017). The experimental site was chosen based on specific criteria, focusing on an area where individual açaí trees were in their third year of cultivation. The trees were planted with a spacing of 5 × 5 m (5 m between rows and 5 m between plants) in a plot of approximately 4200 m^2. This site is part of an association of rural producers involved in an organic production system, where most agricultural output is destined for consumers of organic products and Natura's agroindustry.

The municipality's climate is classified as Af (tropical humid) according to the Köppen–Geiger classification, characterized by the absence of a dry season. The average annual temperature is approximately 26°C, with annual rainfall typically ranging from 2500 to 3000 mm. Historical rainfall data from the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) database shows annual rainfall between 3100 and 3700 mm in the community where the experimental area is located from 2018 to 2022.

According to Auliyani and Wahyuningrum (2021), the data generated by the CHIRPS product can be used to predict annual and monthly rainfall in the study area.

Figure 1 depicts the boundaries of the state (in gray) and municipality (in blue), as well as identifying the location of the experimental area in the city.

Figure 1 - Location of the experiment in Santo Antônio do Tauá, Pará, Brazil.



Collecting and Preparing Soil Samples

Soil samples were collected using random sampling in September 2022. A total of 20 individual samples were combined to form each composite sample (two composite samples in total). The samples were taken from two distinct areas: the canopy projection zone and the interrow. Composite Sample 1 was collected from an area where an application had been made the previous year, while Composite Sample 2 was from an area where no application had been made. Soil samples were extracted from a depth of 0 to 20 cm using a Dutch auge (Filizola et al., 2006). The samples were crushed, sieved, and air-dried for analysis.

The samples were sent to the Solos & Plantas laboratory (IAC Proficiency Seal) for the determination of physical and chemical parameters. The necessary characteristics for conducting the experiment were then identified (Table 1), such as: pH (H2O), aluminum concentrations available (Al^{3+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and phosphorus (P), organic matter content (MO), micronutrients (Fe, Zn, Mn, Mo, B, Cu), density (Ds), and granulometry (sand, silt, and clay content) (Teixeira et al., 2017).

Table 1 - Chemical and physical soil attributes (0-20 cm layer) of two composite samples from the experimental area.

Area 1 (To be corrected)		Area 2 (Uncorrected)	
pH (H_2O)	5.29	pH (H_2O)	5.23
MO (g kg^{-1})	0.29	MO (g kg^{-1})	0.29
Al^{3+} (cmolc dm^{-3})	0.83	Al^{3+} (cmolc dm^{-3})	0.94
$H^{+} + Al^{3+}$ (cmolc dm^{-3})	3.47	$H^{+} + Al^{3+}$ (cmolc dm^{-3})	2.78
Ca^{2+} (cmolc dm^{-3})	0.47	Ca^{2+} (cmolc dm^{-3})	0.41
Mg^{2+} (cmolc dm^{-3})	0.08	Mg^{2+} (cmolc dm^{-3})	0.09
P (mg dm^{-3})	130.1	P (mg dm^{-3})	65.55
K (cmolc dm^{-3})	0.089	K (cmolc dm^{-3})	0.097
S (mg dm^{-3})	1	S (mg dm^{-3})	1
SB (cmolc dm^{-3})	0.64	SB (cmolc dm^{-3})	0.60
CTCT (cmolc dm^{-3})	4.11	CTCT (cmolc dm^{-3})	3.38
CTCt (cmolc dm^{-3})	1.47	CTCt (cmolc dm^{-3})	1.54
V%	15.57	V%	17.75
m%	56.46	m%	61.04
B (mg dm^{-3})	0.18	B (mg dm^{-3})	0.22
Cu (mg dm^{-3})	2.6	Cu (mg dm^{-3})	2.5
Fe (mg dm^{-3})	112	Fe (mg dm^{-3})	147
Mn (mg dm^{-3})	5.5	Mn (mg dm^{-3})	5.4
Zn (mg dm^{-3})	5.0	Zn (mg dm^{-3})	4.0
Ds (g cm^{-3})	1.35	Ds (g cm^{-3})	1.35
Total sand (g kg^{-1})	758	Total sand (g kg^{-1})	758
Silt (g kg^{-1})	46	Silt (g kg^{-1})	46
Clay (g kg^{-1})	196	Clay (g kg^{-1})	196

pH: H_2O; organic matter (MO): Walkley-Black method; Ca, Mg e Al^{3+}: Titration by complexation; $H^{+} + Al^{3+}$: Neutralization titration (NaOH 0.025 mol L^{-1}); P e K^{+}: Mehlich^{-1}; B, Cu, Fe, Mn, Zn: IAC; Total sand, silt and clay: IAC * Manual of Soil Analysis Methods (TEIXEIRA *et al.*, 2017). Note: To be corrected (area 1 to receive liming); Uncorrected (area 2 not limed).

Characterization of Organic Compost

Organic waste compost from the community of Campo Limpo—Santo Antônio do Tauá/PA is the result of the composting process of the following waste: poultry litter, agro-industrial waste such as andiroba bark (*Carapa guianensis* Aubl.), boiler ash, cupuaçu kernel (*Theobroma grandiflorum*), murumuru (*Astrocaryum murumuru*), and priprioca (*Cyperus* *articulatus* L.). The material was obtained following the crushing and pressing of the raw materials employed in the agro-industrial processes. In order to ascertain the quantity of each waste, a ratio of 2:1 was established between the materials with the highest C/N ratio (andiroba bark, boiler ash, murumuru) and the materials with the lowest C/N ratio (poultry litter, priprioca and cupuaçu seeds).

During the composting process, the temperature was managed so that the material was initially heated and, after 30 days, the temperature was stabilized until the compost was completely humified. In addition, the humidity of the material was managed so that there was no paralysis of microbial activity or anaerobic decomposition (lack of oxygen), as well as ensuring the correct aeration of the material.

The composting process took around 90 days to meet the standards required by Normative Instruction No. 61 of July 8, 2020 from the Ministry of Agriculture, Livestock, and Supply/Secretariat of Agricultural Defense (BRASIL, 2020).

After this, the compost samples were sent to the Soils & Plants Laboratory (IAC Proficiency Seal) for physicochemical characterization, where the dry matter, parameters such as pH, density, organic matter, organic carbon, C/N ratio, and macronutrient content were determined (N, P, K, Ca, Mg, S) and micronutrients (B, Cu, Fe, Mn, Zn, Na, Mo. and Al) as described in Table 2.

Table 2 - physico-chemical characterization of the organic compost used in the treatments applied.

Characteristics	Unit	Dry base – 65ºC
Dry matter content	%	50
pH ($CaCl_2$)	-	6.83
Density	g/dm³	0.50

Total Nitrogen	%	2.24
Total Organic Matter	%	67.37
Compostable Organic Matter (Titration)	%	27.59
Organic Matter Resistant to Composting	%	39.78
Total Carbon (Organic and Mineral)	%	39.17
Organic Carbon	%	16.04
Total Mineral Residue	%	32.63
C/N ratio (total C and total N)	-	17/1
C/N ratio (Organic C and Total N)	-	7/1
Total phosphorus (P_2O_5 Total)	%	1.05
Potassium (K_2O Total)	%	0.88
Calcium (Ca Total)	%	1.62
Magnesium (Mg Total)	%	0.63
Sulphur (S Total)	%	0.22
Boron (B Total)	ppm	25.35
Copper (Cu Total)	ppm	89.45
Manganese (Mn Total)	ppm	193.19
Iron (Fe Total)	ppm	3440
Zinc (Zn Total)	ppm	166.15
Sodium (Na Total)	ppm	214.08
Molybdenum (Mo Total)	ppm	7.08

Test conducted in accordance with the Manual of Official Analytical Methods for Fertilizers and Correctives, 2017. Waste: Gravimetric; N - (N - Total) = Raney's League; P, K, Ca, Mg, S, Na, B, Cu, Fe, Mn, Zn, Mo e Al = Nitric digestion; Dt. ICP-OES; Organic Carbon - Volumetric Method Potassium Dichromate. Note: Dry base – 65ºC (extracting water humidity from the sample).

Liming and Fertilization

The amount of lime applied was designed to raise the soil's base saturation to 60% (recommended for the Euterpe oleracea plants). The use of 1.85 t ha^{-1} of dolomitic limestone (PRNT 98.45%) in January 2023. Fertilization, conducted in February 2023, involved the application of organic compost at doses of 2, 4, 6, 8, 10, and 12 kg per treatment within the experimental plots.

Biometric Evaluations

Biometric analyses were conducted in September 2023, with data collected on the following variables: Stipe Height (SH), measured in meters from the leaf insertion point to the root emission; stipe circumference (SC), measured in centimeters at 10 cm above the ground; Circumference at Breast Height (CBH), measured in centimeters at breast height (1.30 m); and number of leaves (NL), determined by counting all leaves present on the stipe, excluding senesced leaves (Oliveira, 2005).

Nutrient Content in Plant Tissue

Plant tissue evaluation was performed using a leaf diagnostic method. Samples were collected from leaf number 5 of the *Euterpe oleracea* plants, which is considered the most representative leaf for assessing the crop's nutritional status in the region (Viégas et al., 2022). An average of six leaflets was collected from each side of the central portion of leaf 5, with the tips removed to obtain a central blade segment measuring 10–20 cm. This sampling was carried out during the harvest period in September 2023, when nutrient export to the crop was at its peak.

The samples were then dried in a forced-circulation oven for 72 h at 65°C, after which they were ground in a Wiley mill and sent to the plant tissue laboratory in the soil science department of the “Luiz de Queiroz” School of Agriculture at the University of São Paulo—Esalq/USP for the determination of macro and micronutrients (Miyazawa et al., 2009).

Chlorophyll Content

The chlorophyll index was estimated using the SPAD-502 portable chlorophyll meter on the same leaflets used for the gas exchange measurements (Leaf N° 5) in September 2023. The SPAD-502 readings were taken at three points on the leaf's central vein and on the adaxial side of the leaf, and the averages were calculated.

Gas Exchange

The gas exchange parameters were estimated in September 2023 on the leaflets of the fifth physiologically mature and fully expanded leaf, from apex to base. These were: the net CO_2 assimilation rate (*A*), stomatal conductance to water vapor (*gs*), and the transpiration rate (*E*); intercellular CO_2 concentration (Ci), intrinsic carboxylation efficiency (*A/Ci*), and the instantaneous efficiency of water use (*A/E*).

These analyses were carried out when the plant was in ambient conditions for these processes, using a portable infrared gas analyzer of the open system type (LI-6400 XT, LI-COR, Lincoln, NE) under an external CO_2 concentration of 400 μmol mol^{-1} of air and artificial photosynthetically active radiation (PAR) of 1000 μmol of photons m^{-2} s^{-1}. The measurement interval (9 to 11 a.m.) was adjusted according to the results obtained from the diurnal gas exchange curve for the species.

Experimental Design

The experimental design used was randomized blocks in a 7 × 2 factorial scheme, with factor 1 being the six doses (2, 4, 6, 8, 10, and 12 kg per plant) of organic compost as well as the control treatment and factor 2 the conditions of with and without liming, with 14 treatments distributed in six replications, totaling 84 experimental units, in which each experimental plot had two *Euterpe oleracea* plants.

Conduction of the Experiment and Data Analysis

Phytosanitary management was conducted during this research to control aphids and mealybugs on some plants, using neem oil at a ratio of 200 mL per 20 L of water. The mixture was applied with a 20-L knapsack sprayer. Lime and top-dressing fertilizer were applied to the soil, and invasive plants were removed within the projection area of the plant's crown. Fifty percent of the fertilizer was applied 30 days after liming, with the remaining 50% applied 15 days later.

The data from this study were subjected to the necessary assumptions, such as normality and homoscedasticity tests, followed by analysis of variance (ANOVA), and the means were compared using the Scott-Knott test ($p \leq 0.05$) and regression analysis. To present the obtained data, means and standard deviations were calculated, and graphs and tables were created using Microsoft Excel (Microsoft 365 version) and SigmaPlot 10.0. Pearson correlation analysis was conducted to assess relationships between variables. Principal component analysis (PCA) was also employed for data evaluation. All statistical analyses were performed using R software, version 4.2.1 (R Core Team 2022).

Results

Biometric Evaluations

The results obtained, with a significant level of 1% for each equation, both with and without the use of agricultural lime, indicate that the highest stipe height (HS) was observed in the treatment that received 8 kg of organic compost with liming, providing an average height of approximately 3.6 m (41.66% gain compared to the combination that provided the lowest result) and 3.26 m, sequentially, as shown in Figure 2A. The lowest average values were observed in control treatment and the treatment with 12 kg of compost, ranging from 2.18 to 2.37 m and from 2.10 to 2.74 m, respectively. In addition, it was determined that the optimum dose of this organic fertilizer (maximum biological potential) is 6.33 kg with liming.

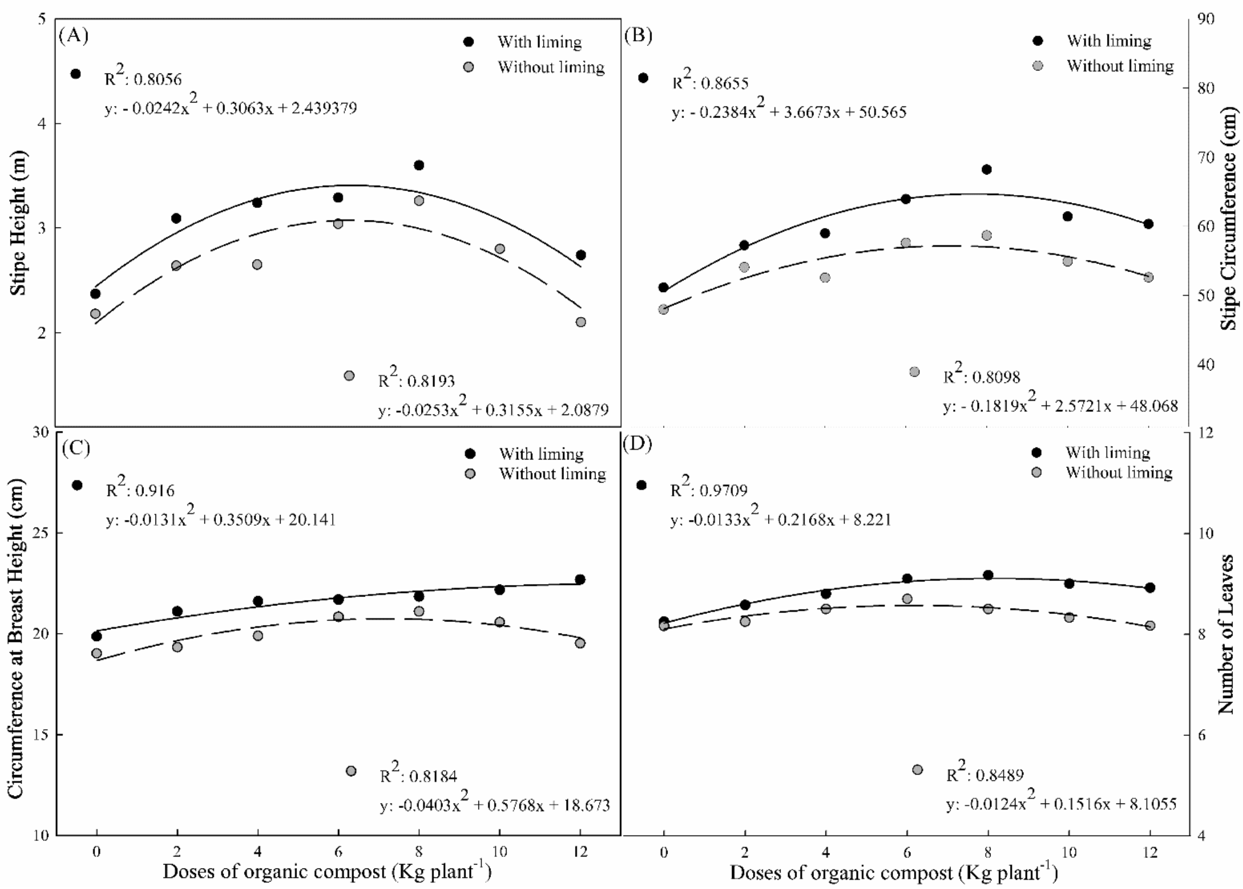
For the SC variable, the use of the corrective practice together with the 8 kg dose of compost led to a higher result, with around 68.22 cm (29.71% gain compared to the combination that provided the lowest result). The lowest values were recorded for the control treatment and the 2 kg dose, ranging from 51.12 to 57.25 cm. The optimum dose for this combination is 7.69 kg of compost. In the absence of liming, the dose of 8 kg of organic fertilizer stood out, providing the highest, with an average value of 58.63 cm. On the other hand, the lowest values were observed in control treatment and with the 4 kg of compost, with average values varying between 47.95 and 52.54 cm (Figure 2B).

With regard to the circumference at breast height (CBH), the 10 and 12 kg doses of compost, combined with liming, showed the best results, with averages varying between 22.17 and 22.68 cm (16.13%) gain compared to the combination that provided the lowest result. On the other hand, the lowest results were seen in the control treatment and the 2-kg dose, with averages varying between 19.86 and 21.10 cm. The maximum dose was 13.39 kg of compost. In contrast, for the combination without liming, the dose of 6 kg of compost provided the highest average (20.83 cm), while the control treatment resulted in an average value of 19.02 cm (Figure 2C).

In the NL variable, both with and without the use of agricultural lime, the highest values were observed in the treatment that received 8 kg of organic compost, with an average of around nine leaves (11.01% gain compared to the combination that provided the lowest result), as shown in Figure 2. The control treatment had the lowest average values, with around eight leaves. The ideal dose of compost for this variable is 8.15 kg with liming.

In addition, the chelating effect of organic matter means that these nutrients, which are essential for plant growth, are released more slowly than with chemical fertilization.

Figure 2 - Biometric variables Stipe Height (A), Stipe Circumference (B), Circumference at Breast Height (C) and Number of Leaves (D) of *Euterpe oleracea* plants as a function of treatments.



Nutritional Assessment in Plant Tissue

The average leaf nitrogen (N) concentration was higher in the treatments with 8 and 10 kg of organic compost with liming, 10 and 12 kg of organic compost without liming, ranging from 31.80 to 37.13 g·kg^{-1}. In contrast, the lowest concentrations were observed in treatments with 2, 4, and 6 kg of organic compost with liming, without fertilizer application with liming and 4 kg of organic compost without liming, ranging from 2.37 to 7 g·kg^{-1}. For P, there were no significant differences in the average concentrations, which ranged from 0.94 to 1.01 g·kg^{-1}. Regarding potassium (K), the highest concentrations were observed in the treatments with 6, 8, and 10 kg of organic compost with liming, with an average of 2 g·kg^{-1} for all three. In contrast, the other treatments (2, 4 and 12 kg of organic compost with liming; 2, 4, 6, 8, 10 and 12 kg of organic compost without liming; and without fertilizer application without liming) exhibited lower average concentrations, ranging from 0.9 to 1.33 g·kg^{-1} (Table 3).

For Ca, the highest concentrations were observed in the treatments with 2, 4, 6, 8 and 10 kg of organic compost with liming, without fertilizer application with liming, and 12 kg of organic compost without liming, with values ranging from 2.43 to 3 g·kg^{-1}. The lowest concentrations were found in the treatments with 12 kg of organic compost with liming, 2, 4, 6, 8 and 10 kg of organic compost without liming, and without fertilizer application without liming, ranging from 2 to 2.33 g·kg^{-1}. For Mg, the highest foliar concentrations were recorded in the treatments with 8 kg of organic compost with liming and without fertilizer application with liming, with values ranging between 0.57 and 0.63 g·kg^{-1}. Conversely, the lowest values were observed in the treatments with 12 kg of organic compost with liming: 2, 4, 6, 8, 10 and 12 kg of organic compost without liming, with concentrations varying between 0.37 and 0.47 g·kg^{-1}. As for S, there were no significant differences among treatments, with values ranging from 2.83 to 3.57 g·kg^{-1} (Table 3).

Considering the average foliar concentrations of macronutrients in this study, the decreasing order for açaí palms was N > S > Ca > K > P > Mg. Viégas et al. (2022) analyzing the fifth leaf of the açaí palm, reported a different order: N > K > Ca > S > P > Mg. For coconut palms, (Saldanha et al., 2017) observed the following decreasing order: N > Ca > K > Mg > P > S.

Table 3 – Average concentrations, standard deviation and coefficient of variation of primary and secondary macronutrients in Euterpe oleracea plants leaves, depending on the treatments.

Treatments	N	P	K	Ca	Mg	**S**

	g.kg^{-1}					
T1	2.37 ± 0.51c	0.99 ± 0.01a	1.00 ± 0.00b	2.43 ± 0.12a	0.50 ± 0.00b	3.17 ± 0.31a
T2	3.53 ± 0.20c	1.01 ± 0.07a	1.00 ± 0.00b	2.97 ± 0.06a	0.53 ± 0.06b	3.03 ± 0.21a
T3	4.25 ± 0.40c	0.98 ± 0.02a	2.00 ± 0.0a	2.57 ± 0.51a	0.50 ± 0.00b	3.00 ± 0.66a
T4	33.60 ± 2.00a	1.00 ± 0.04a	2.00 ± 0.00a	2.67 ± 0.58a	0.63 ± 0.06a	2.83 ± 0.45a
T5	33.93 ± 3.43a	0.97 ± 0.03a	2.00 ± 0.00a	2.67 ± 0.57a	0.50 ± 0.00b	3.37 ± 0.40a
T6	21.00 ± 4.00c	0.95 ± 0.02a	1.33 ± 0.58b	2.00 ± 0.00b	0.46 ± 0.06c	3.53 ± 0.20a
T7	7.00 ± 1.00c	0.98 ± 0.02a	1.33 ± 0.50b	3.00 ± 0.00a	0.57 ± 0.11a	3.00 ± 0.53a
T8	22.20 ± 2.00b	0.96 ± 0.02a	1.00 ± 0.00b	2.00 ± 0.00b	0.47 ± 0.06c	2.93 ± 0.15a
T9	13.20 ± 3.00c	0.97 ± 0.01a	1.00 ± 0.01b	2.33 ± 0.58b	0.43 ± 0.05c	3.23 ± 0.40a
T10	24.60 ± 4.00b	0.97 ± 0.01a	0.93 ± 0.11b	2.00 ± 0.00b	0.40 ± 0.00c	3.00 ± 0.17a
T11	25.20 ± 1.00b	0.99 ± 0.02a	0.97 ± 0.06b	2.00 ± 0.00b	0.40 ± 0.01c	3.57 ± 0.25a
T12	37.13 ± 2.90a	0.99 ± 0.01a	1.00 ± 0.00b	2.00 ± 0.00b	0.40 ± 0.01c	3.53 ± 0.38a
T13	31.80 ± 3.00a	0.95 ± 0.02a	1.00 ± 0.00b	2.67 ± 0.58a	0.37 ± 0.05c	3.57 ± 0.40a
T14	25.13 ± 0.61b	0.94 ± 0.06a	0.9 ± 0.17b	2.00 ± 0.00b	0.50 ± 0.00b	3.40 ± 0.27a
CV (%)	11.79	3.30	18.55	13.48	10.36	11.53

Digestion: sulphuric (N); nitroperchloric (P, K, Ca, Mg, S, Cu, Zn, Mn and Fe); incineration (B). Determinations: Colorimetry (P and B); turbidimetry (S): flame photometry (K); atomic absorption spectrophotometry (k, Ca, Mg, Cu, Zn, Mn and Fe). (Manual of Chemical Analysis of Soils, Plants and Fertilizers. 2nd revised and expanded edition. Embrapa, 2009). Note: Averages followed by the same letter in a column show no significant difference.

The highest concentration of leaf B was observed in the treatment with 10 kg of organic compost without liming, averaging 55.43 mg·kg^{-1}. In contrast, the lowest concentrations were found in the treatments with 2 kg of organic compost, both with and without liming, ranging from 19.27 to 19.43 mg.kg^{-1}. There were no significant differences between treatments regarding foliar Fe concentrations, with averages ranging from 1 to 1.67 mg·kg^{-1}. For foliar Mn concentrations, higher values were observed in the treatments with 2, 4, 6, 8 and 10 kg of organic compost with liming; without fertilizer application with liming; 8 kg and 12 kg of organic compost without liming; and without fertilizer application without liming, with averages ranging from 2.67 to 3.67 mg·kg^{-1}. In contrast, the lowest values were recorded in the treatments with 12 kg of organic compost with liming: 2, 4, 6 and 10 kg of organic compost without liming, with averages ranging from 0.93 to 1.93 mg·kg^{-1} (Table 4).

Considering the average foliar concentrations of the micronutrients in this study, the decreasing order for the *Euterpe oleracea* plants was B > Mn > Fe.

Table 4 - Mean concentration, standard deviation and coefficient of variation of micronutrients in *Euterpe oleracea* plants leaves, as a function of treatment.

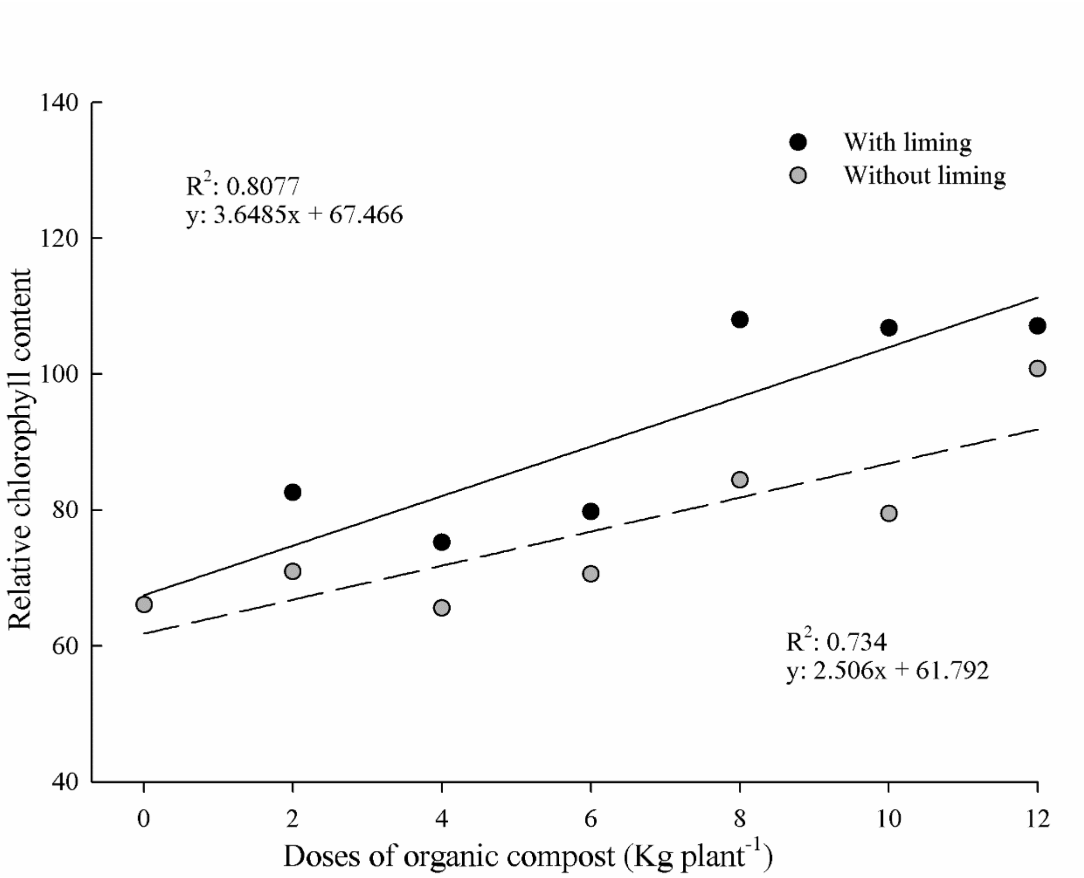
Treatments	B	Fe	Mn
		mg.kg^{-1}	
T1	48.80 ± 3.46b	1.67 ± 0.57a	3.67 ± 0.57a
T2	47.23 ± 0.89b	1.27 ± 0.46a	2.83 ± 0.76a
T3	41.93 ± 1.15c	1.63 ± 0.55a	2.67 ± 0.57a
T4	24.47 ± 0.58e	1.06 ± 0.11a	2.67 ± 0.15a
T5	36.57 ± 1.15d	1.00 ± 0.00a	2.67 ± 0.58a
T6	19.27 ± 1.15f	1.00 ± 0.00a	0.93 ± 0.11b
T7	38.13 ± 7.40d	1.33 ± 0.58a	3.00 ± 1.00a
T8	19.43 ± 1.10f	1.00 ± 0.01a	1.07 ± 0.11b
T9	23.30 ± 1.73e	1.00 ± 0.00a	1.93 ± 0.11b
T10	34.07 ± 2.31d	1.00 ± 0.00a	0.97 ± 0.06b
T11	29.93 ± 1.85e	1.00 ± 0.01a	2.67 ± 0.57a
T12	55.43 ± 4.62a	1.00 ± 0.01a	1.00 ± 0.00b
T13	26.27 ± 2.31e	1.00 ± 0.02a	3.33 ± 0.60a
T14	24.87 ± 3.21e	1.33 ± 0.57a	2.67 ± 0.58a
CV (%)	8.37	26.70	26.81

Digestion: sulphuric (N); nitroperchloric (P, K, Ca, Mg, S, Cu, Zn, Mn and Fe); incineration (B). Determinations: Colorimetry (P and B); turbidimetry (S): flame photometry (K); atomic absorption spectrophotometry (K, Ca, Mg, Cu, Zn, Mn and Fe) (Manual de Análises Químicas de Solos, Plantas e Fertilizantes. 2nd revised and expanded edition. Embrapa, 2009). Note: Averages followed by the same letter in a column do not differ significantly according to the Scoot-Knott test (p-value ≤ 0.05).

Evaluation of Relative Chlorophyll Content

The results for relative chlorophyll content (SPAD index), evaluated at a 1% significance level, revealed that the highest values were positively influenced by the combination of liming and an 8 kg dose of organic compost, with an average of 107.97 SPAD units. The lowest value was recorded in control treatment, with 66.07 SPAD units. In treatments without liming, the application of 12 kg of compost yielded the highest average, approximately 100 SPAD units, while the lowest average, 66.03 SPAD units, was again observed in the control treatment. In the absence of liming, the amount of 12 kg of compost provided the highest average, with approximately 100 SPAD units and the lowest average result was observed in the control treatment, with 66.03 SPAD units.

Figure 3 - Variation in relative chlorophyll content (SPAD index) in the fifth leaf of açai trees.



Evaluation of Gas Exchange

Regarding the *A* (CO_2 assimilation rate) averages, no statistical differences were observed among the treatments, with values ranging from 7.25 to 8.98 µmol $CO_2/m^2.s^{-1}$. For g_s (stomatal conductance to water vapor), the highest results were obtained in the treatments with 6 kg of organic compost with liming and 6 kg of organic compost without liming, with averages ranging from 62.55 to 62.58 mmol.$H_2O/m^2.s^{-1}$. The lowest g_s values were recorded in treatments with 4 kg of organic compost with liming, 8 kg of organic compost without liming, 12 kg of organic compost with liming, and without fertilizer application with liming, with averages ranging from 34.39 to 38.90 mmol.$H_2O/m^2.s^{-1}$. For *E* (transpiration), the highest averages were observed in the 6 kg of organic compost with liming and 6 kg of organic compost without liming treatments, with values between 2.09 and 2.10 mol.$H_2O/m^2.s^{-1}$. Conversely, the lowest *E* values were found in the treatments with 4 kg of organic compost with liming, 8 and 12 kg of organic compost with liming, without fertilizer application with liming and without fertilizer application without liming, ranging from 1.31 to 1.43 mol.$H_2O/m^2.s^{-1}$ (Table 5).

Table 5 - Means, standard deviation and coefficient of variation of net CO_2 assimilation rate (*A*), stomatal conductance to water vapor (g_s), transpiration (*E*) in young *Euterpe oleracea* plants under doses of organic fertilization, in the presence and absence of liming.

Treatments	*A*	g_s	*E*
	µmol de $CO_2/m^2.s^{-1}$	mmol.$H_2O/m^2.s^{-1}$	mol.$H_2O/m^2.s^{-1}$
T1	8.98 ± 2.5a	58.56 ± 0.58b	1.81 ± 0.02c
T2	6.68 ± 8.8a	36.67 ± 1.15e	1.32 ± 0.04e
T3	7.67 ± 0.96a	62.55 ± 2.33a	2.09 ± 0.06a
T4	6.72 ± 0.84a	38.90 ± 1.74e	1.36 ± 0.02e
T5	7.65 ± 0.42a	57.10 ± 2.68b	1.96 ± 0.05b
T6	7.39 ± 2.06a	37.67 ± 4.93e	1.43 ± 0.21e
T7	5.64 ± 0.79a	34.39 ± 2.11e	1.31 ± 0.16e
T8	8.21 ± 0.59a	51.17 ± 1.75d	1.75 ± 0.04d
T9	7.68 ± 1.14a	54.95 ± 1.63c	1.88 ± 0.07c
T10	8.50 ± 1.03a	62.58 ± 1.45a	2.10 ± 0.05a
T11	7.91 ± 1.36a	56.76 ± 1.90b	1.83 ± 0.04c
T12	7.36 ± 1.13a	49.25 ± 1.64d	1.68 ± 0.06d
T13	7.25 ± 1.51a	58.91 ± 1.89b	1.92 ± 0.05b
T14	7.44 ± 0.74a	53.73 ± 1.16c	1.39 ± 0.03e
CV (%)	15.83	4.12	4.55

Note: Averages followed by the same letter in a column do not differ significantly from each other.

For *Ci* (intercellular CO_2 concentration), the highest value was observed in the treatment with 10 kg of organic compost with liming, averaging 324.62 µmol CO_2 mol^{-1} air. The lowest averages, ranging from 130.53 to 137.96 µmol $CO_2 \cdot mol^{-1}$ air, were recorded in the treatments with 2, 4 and 12 kg of organic compost with liming; without fertilizer application with liming; and 8, 10 and 12 kg of organic compost without liming.

Regarding A/E (instantaneous water use efficiency), there were no statistical differences among treatments, with averages ranging from 3.65 to 5.35. For *A/Ci* (intrinsic carboxylation efficiency), the highest values, ranging from 0.04 to 0.07, were found in the treatments with 2 4, 6 and 12 kg of organic compost with liming; and 2, 4, 6, 8, 10 and 12 kg of organic compost without liming. The lowest value, an average of 0.02, was observed in treatment T5 (Table 6).

Table 6 - Means, standard deviation and coefficient of variation of intercellular CO_2 concentration (*Ci*),

instantaneous water use efficiency (*A/E*) and intrinsic carboxylation efficiency (*A/Ci*) in young *Euterpe oleracea* plants under doses of organic fertilization, in the presence and absence of liming.

Treatments	*Ci*	*A/E*	*A/Ci*
	μmol CO_2 mol^{-1} air	-	-
T1	131.81 ± 0.86e	4.97 ± 1.41a	0.07 ± 0.02a
T2	137.96 ± 1.12e	5.07 ± 0.73a	0.04 ± 0.01a
T3	148.62 ± 1.51c	3.65 ± 0.36a	0.05 ± 0.006a
T4	173.17 ± 2.83b	4.94 ± 0.55a	0.03 ± 0.005b
T5	324.62 ± 2.34a	3.90 ± 0.31a	0.02 ± 0.001c
T6	130.53 ± 4.45e	5.21 ± 7.43a	0.06 ± 0.01a
T7	135.39 ± 1.63e	4.36 ± 1.05a	0.04 ± 0.006b
T8	150.65 ± 1.04c	4.70 ± 0.38a	0.05 ± 0.01a
T9	144.83 ± 3.79d	4.07 ± 0.45a	0.05 ± 0.01a
T10	142.74 ± 2.09d	4.03 ± 0.42a	0.06 ± 0.01a
T11	132.76 ± 2.67e	4.33 ± 0.84a	0.06 ± 0.01a
T12	131.97 ± 6.73e	4.37 ± 0.64a	0.06 ± 0.01a
T13	135.04 ± 1.75e	3.78 ± 0.80a	0.05 ± 0.01a
T14	168.34 ± 5.54b	5.35 ± 0.49a	0.03 ± 0.004b
CV (%)	2.1	16.61	17.07

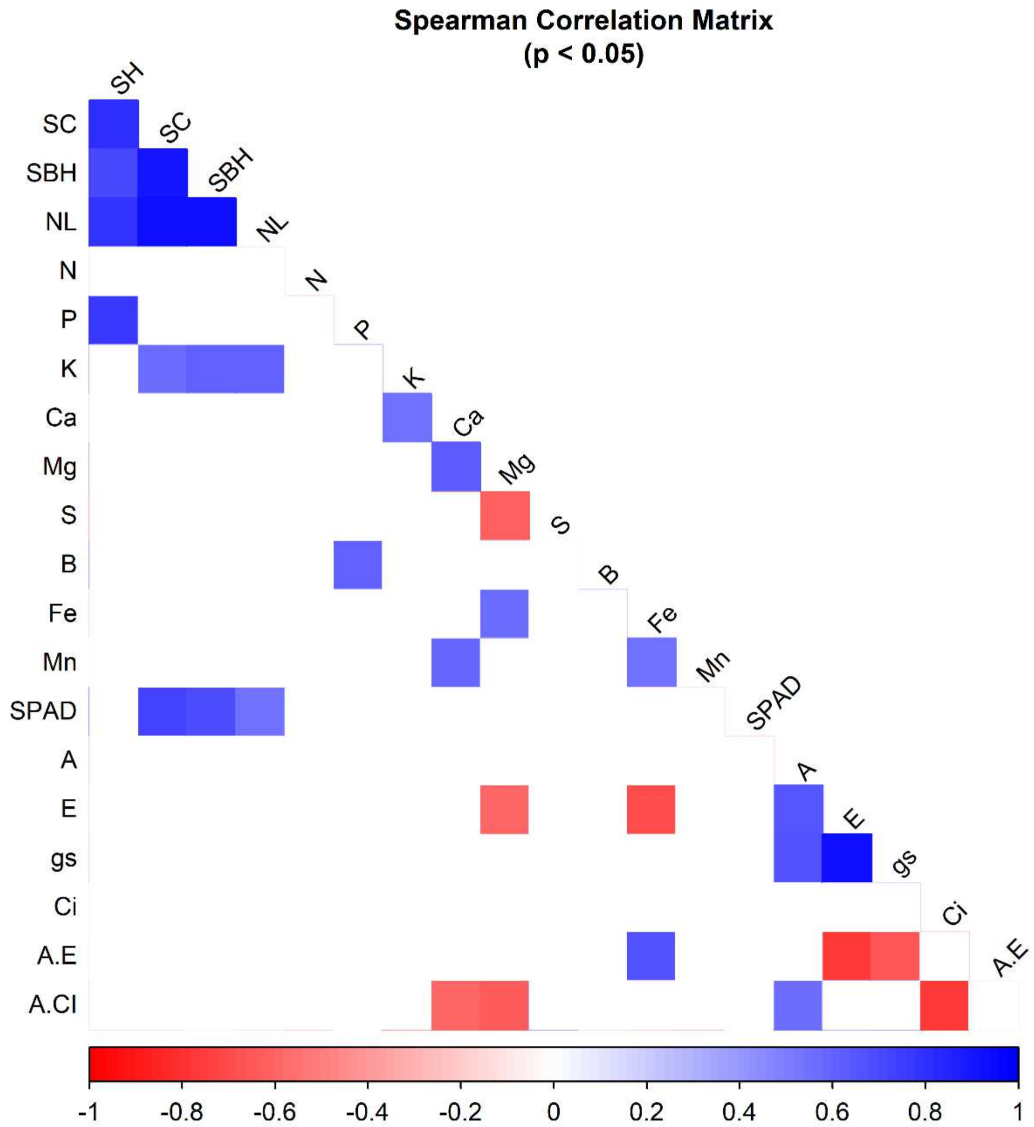
Note: Averages followed by the same letter in a column do not differ significantly from each other.

Correlation and PCA

Regarding biometric variables, stipe height exhibited a significant correlation with SC, circumference at breast height, NL, and phosphorus levels. SC, in turn, showed significant correlations with stipe height, circumference at breast height, NL, potassium levels, and relative chlorophyll content (SPAD index). Similarly, circumference at breast height was significantly correlated with stipe height, SC, NL, potassium levels, and SPAD index. Lastly, the NL demonstrated significant correlations with stipe height, SC, circumference at breast height, potassium levels, and SPAD index (Figure 4).

Figure 4. Pearson's Correlation Matrix between the variables Stipe Height (SH), Stipe Circumference (SC), Circumference at Breast Height (CBH), Number of Leaves (NF), Nitrogen (N), Phosphorus (P), Potassium (K),

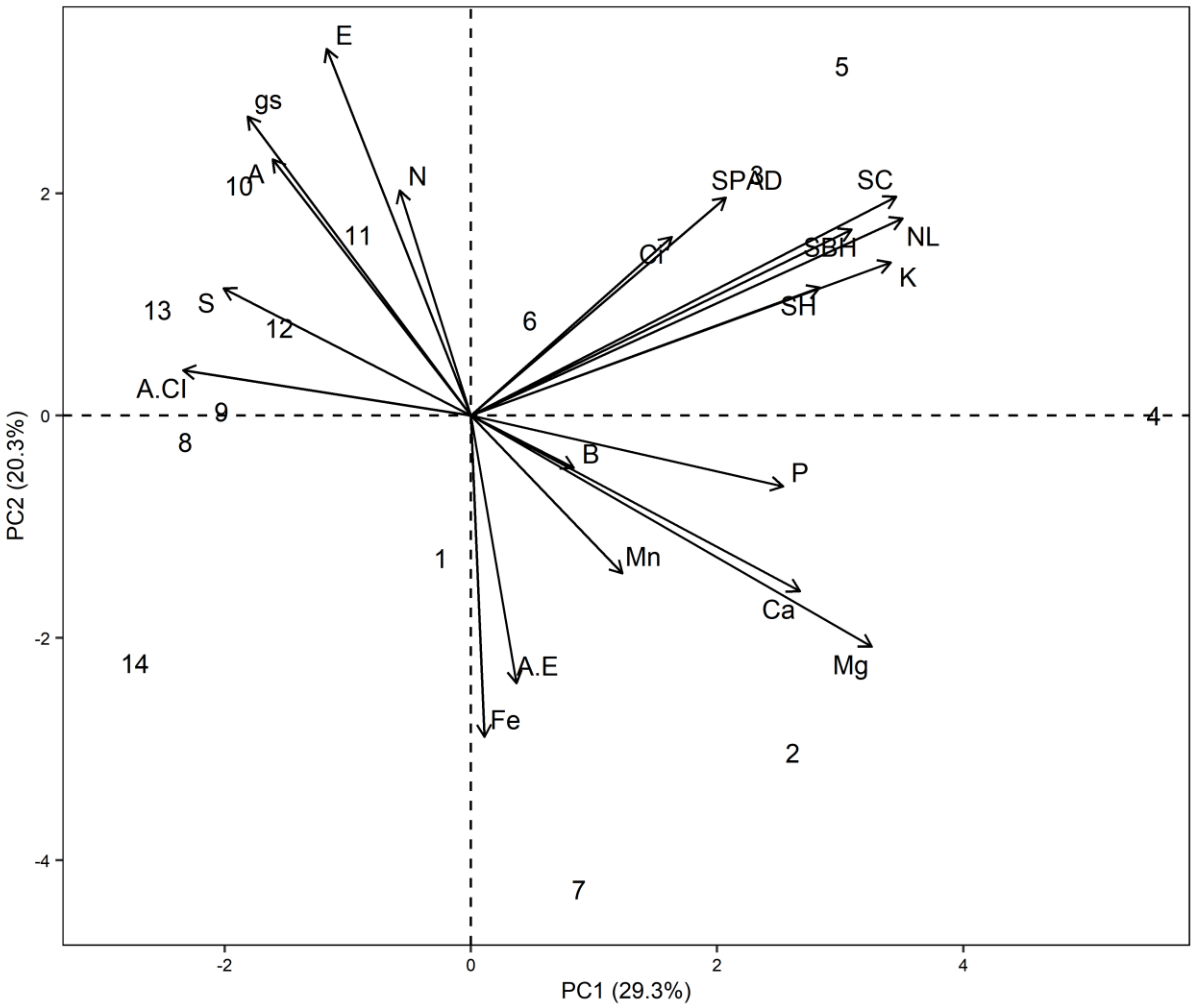
Calcium (Ca), Magnesium (Mg), Sulphur (S), Boron (B), Iron (Fe), Manganese (Mn), Relative Chlorophyll Content (SPAD), Net CO_2 Assimilation (*A*), Stomatal Conductance to Water Vapor (g_s), Transpiration (*E*), Intercellular CO_2 Concentration (*Ci*), Instantaneous Water Use Efficiency (*A/E*) and Intrinsic Carboxylation Efficiency (*A/Ci*).



According to the PCA (Figure 5), conducted to better understand the effects of the treatments applied in this study, the first principal component (Dim 1) accounted for 29.33% of the data variability. This component was primarily influenced by circumference at breast height, NL, potassium, and calcium, which had the greatest positive effects. In contrast, instantaneous water uses efficiency, phosphorus, and boron had the smallest positive effects, while sulfur and assimilation-to-internal CO_2 ratio had the smallest negative effects.

Figure 5 - Principal components as a function of treatments and variables Stipe Height (SH), Stipe Circumference

(SC), Circumference at Breast Height (CHH), Number of Leaves (N. Leaves), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnetism (Mg), Sulfur (S), Boron (B) Leaves),Iron (Fe), Manganese (Mn), Relative Chlorophyll Content (SPAD), Net CO_2 Assimilation (A), Stomatal Conductance to Water Vapor (g_s), Transpiration (*E*), Intercellular CO_2 Concentration (*Ci*), Instantaneous Water Use Efficiency (*A/E*) and Intrinsic Carboxylation Efficiency (*A/Ci*) in acai tree.



Discussion

Biometric Evaluations

The addition of organic compost to the soil increases stipe height by enhancing the soil's physical and biological properties (Adetunji et al., 2020; Dawson & Smith, 2007). These improvements support better root development, allowing plants to more effectively access soil nutrients. Furthermore, organic compost contains essential nutrients that promote plant growth (Möller & Schultheiß, 2015). For example, nitrogen is an essential nutrient for vegetative growth because it is required for cell division, which involves DNA replication. This process demands a significant amount of nucleotides, whose components include nitrogenous bases

(Taiz et al., 2017). Iron is also a fundamental micronutrient for promoting plant growth, as it is essential in the photochemical phase of photosynthesis and is directly involved in the production of photoassimilates (Zhang et al., 2019).

Nogueira and Conceiçao (2000) studying the growth of açaí trees in palm heart management and cultivated in the floodplain of the Amazon estuary, found stipe heights of 1.94 and 3.15 m at 36 and 48 months of age, respectively. Condé et al. (2020) found higher stipe heights in the management of açai trees of different ages in a clump regime and at 5 × 5 m spacing arrangements.

Organic compost increased SC, possibly due to the supply of Ca^{2+} ions and the micronutrient B, which play important structural roles, as they form part of the cell wall, promoting better cell division and, consequently, greater SC, as well as greater stipe height. In addition to maintaining the integrity of various organelles and influencing various processes in the plant, it is also an enzyme activator (Fagan et al., 2016; Kohli et al., 2023; Prado, 2021). In addition, SC increased due to the Mg^{2+} ions supplied by the treatments, which are important for the growth of the roots and aerial part of the plant, since they play various roles in the activation of enzymes related to cellular respiration and photosynthesis, fundamental processes for plant growth (Chen et al., 2018; Taiz et al., 2017). Almeida et al. (2018) found greater growth in stipe diameter, which is related to SC, in the monoculture system up to 360 days after transplanting.

A large amount of organic compost increased the results in circumference at breast height, especially in the presence of the corrective practice that neutralizes toxic elements and increases the pH to around 5.5 and 6.5, which increases the solubility of essential nutrients (Campos et al., 2022; Jiang et al., 2018; Zhang et al., 2020), provided by organic compost, which is a “nutrient reservoir” (Brady & Weil, 2010; Gulhane et al., 2023; İnik et al., 2023).

Organic compost had a positive effect on the NL, possibly due to the supply and greater solubility of N, which is the main constituent of proteins, coenzymes, membrane components, chlorophyll, as well as organic metabolites such as amino acids, amines, and phytohormones, important processes in the development of the aerial part and leaf growth (Bang et al., 2021). S was also fundamental in increasing the NL because it is a component of vitamins, coenzymes, and chlorophyll, which enables photosynthesis. It is involved in protein synthesis and is fundamental for plant growth, development, and quality (Narayan et al., 2023; Zenda et al., 2021). Fe and Zn are also fundamental micronutrients for this variable, as they are related to greater chlorophyll synthesis and plant growth promotion (Nandal & Solanki, 2021; Zhang et al., 2019).

It should be noted that all the essential nutrients, macro- and micronutrients, have a positive influence on the biometric variables since Liebig's Law of the Minimum states that crop production is limited by the least amount of nutrients in the soil (Brady & Weil, 2010; Lepsch, 2021; Raij, 2011). Gas exchange is also fundamental for plant growth (Pereira et al., 2014).

Nutritional Assessment in Plant Tissue

N is absorbed by plants in the forms of nitric (NO_3^-), ammoniacal (NH_4^+) and organic N in the form of peptides and amino acids (Ganeteg et al., 2017), with nitrate being the most predominant form (Prado, 2021a). Nitrogen is a highly mobile nutrient in plants, accumulating in the youngest tissues (Fernandes et al., 2018). It is involved in many fundamental plant processes such as photosynthesis and cellular respiration (Malavolta, 2006). Ribeiro (2017) identified foliar concentrations of 23 $g.Kg^{-1}$ of N in adult acai tree in the Eastern Amazon. Viégas et al. (2022) evaluating leaf number 5 in acai trees 4 years and 8 months old, found 25.6 $g.kg^{-1}$ of N. In young 2-year-old acaí trees fertilized with NPK, the foliar N concentration was 13.1 $g.kg^{-1}$ of N (Cordeiro, 2011).

P is a nutrient with high mobility in plant tissue (Fernandes et al., 2018), it is an important element for energy metabolism (ATP, NADPH) and phospholipids in cell membranes (Bang et al., 2021), as well as being essential for root development and improving plant vigor (Malhotra et al., 2018). Cordeiro (2011) determined foliar P levels of 1.0 $g.kg^{-1}$ in two-year-old acai tree under NPK fertilization. Evaluations of 8-month-old BRS Pai d'Égua cultivar acai trees under complete fertilization, grown in a greenhouse, indicated 1.0 $g.kg^{-1}$ of P (Araújo et al., 2019). Lindolfo et al. (2020), studying 9.5-year-old plants sampled from leaf number 6, found a P content of 1.4 $g.kg^{-1.}$

Palm trees, especially the coconut palm (*Cocus Nucifera*), are not very responsive to phosphate fertilization. This may be related to the crop's adaptation to the low availability of the element in tropical Amazonian soils, the mineralogy of which consists mainly of (hydro)oxides of Fe (hematite or goethite), Al (gibbsite) and kaolinite in the clay fraction, and quartz in the sand fraction. Thus, P can be available in solution or unavailable (P-labile), with P adsorbed on the aforementioned oxides (Fe_2O_3-P, Al_2O_3-P), or precipitated (Fe-P, Al-P), or totally unavailable in the non-labile form (Fontes & Alleoni, 2006; Hartemink & Barrow, 2023; Pavinato et al., 2020; Penn & Camberato, 2019).

K is also a highly mobile element in plant tissues (Fernandes et al., 2018), acting in the regulation of osmotic processes, enzyme activation and nutrient transport, as well as being involved in the general development of the plant (Johnson et al., 2022; Sardans & Peñuelas, 2021). Viegas et al. (2009) studied 10-month-old acai trees under complete fertilization and found a K content of 3.5 $g.kg^{-1}$ at 10 months of age. In a study of 2-year-old açai trees that received NPK fertilization in the municipality of Tome-Açú, concentrations of 4.6 g.kg-1 were found in the leaflets (Cordeiro, 2011). Viégas et al. (2022) studied 4-year-old and 8-month-old açai trees and found a K content of 6.8 g $kg\text{-}^{1}$ in the fifth leaf.

Ca is a nutrient with limited mobility due to its low solubility and concentration in the phloem of plants (Prado, 2021a). It is an important nutrient for stabilizing cell walls and acts as a secondary messenger in many signaling pathways, affecting cell division, stem elongation and maintaining the plant's structural integrity (Hawkesford et al., 2012; Kour et al., 2023)

In a study of 4-year-old and 8-month-old açai trees, leaf number 5 was sampled and found to contain 4.8 $g.kg^{-1}$ of Ca (Viégas et al., 2022). In adult plants from native floodplain populations in Marajó/Pa, the Ca concentration found was 4.4 $g.kg^{-1}$ (Brasil et al., 2009). In a study of 2-year-old açai trees fertilized with NPK, a Ca concentration of 1.9 $g.kg^{-1}$ was found.

Mg is a mobile element in the phloem of plants, since a fundamental part of Mg is soluble (Prado, 2021b). It is a nutrient that aids plant growth and development and is a central component of chlorophyll, which influences photosynthesis (Chen et al., 2018; Guo et al., 2016; Tian et al., 2021). Viégas et al. (2022) studied plants that were 4 years and 8 months old and found an average concentration of 0.1 $g.kg^{-1}$ of Mg in leaf number 5. In a study in the municipality of Tome-Áçu/Pa on 9.5-year-old acai trees, an average concentration of 1.0 $g.kg^{-1}$ of Mg was found in leaf number 6 (Lindolfo et al., 2020). Cordeiro (2011) observed a concentration of 0.5 $g.kg^{-1}$ of Mg in 2-year-old açai trees under NPK fertilization.

As for S, it is a nutrient with little redistribution in plant tissue, meaning it is not very mobile in the plant (Prado, 2021). In addition, this element is a component of amino acids, vitamins and coenzymes, protein synthesis and chlorophyll, and is therefore important for photosynthesis, making it essential for plant growth, development and quality (Narayana *et al*., 2023; Zenda *et al*., 2021). Ribeiro et al. (2020) studied 7-year-old fertirrigated açai plants in the municipality of Tome-Áçu/Pa and found a leaf concentration of 3.1 $g.kg^{-1}$ of S. In acai trees that were 4 years and 8 months old, Viégas *et al*. (2022) found that leaf number 5 had a concentration of 2.7 $g.kg^{-1}$ of S. In 2-year-old açai trees that received NPK fertilization, in the municipality of Tomé-Áçu, the concentration of 1.9 of S (Cordeiro, 2011).

B is an element that is poorly redistributed in plants, as it is considered to have low mobility in the phloem, similar to Ca (Prado, 2021). This nutrient plays a crucial role in regulating the structural and membrane integrity of the cell wall and plasma membrane. It facilitates ion mobility across membranes, supports cell division and elongation, and is essential for reproductive processes such as pollen formation and flower retention. Additionally, it is involved in the synthesis of carbohydrates and proteins (Camacho-cristóbal et al., 2008; Hänsch & Mendel, 2009; Kohli et al., 2023). Lindolfo *et al*. (2020) evaluated 6-year-old açai trees sampled on leaf 6 and found an average concentration of 14.90 $mg.kg^{-1}$ of B. In 7-year-old fertigated açai trees, sampled on leaves 4 and 5, a concentration of 51.00 $mg.kg^{-1}$ of B was found. In 2-year-old acai trees in the municipality of Tomé-Áçu, which received NPK fertilization, a B concentration of 17.00 $mg.kg^{-1}$ was found.

Fe is poorly redistributed through the plant's phloem, meaning it has low mobility (Prado, 2021). This nutrient is crucial for chlorophyll synthesis and is essential for maintaining the structure and function of chloroplasts. It plays a key role in the electron transport system, the formation of clusters, and the photosynthetic apparatus, highlighting its direct involvement in photosynthetic activity and, consequently, plant productivity (Rout & Sahoo, 2015; Zhang et al., 2019). In 4-year-old and 8-month-old açai trees sampled in the fifth leaf, a concentration of 118 $mg.kg^{-1}$ of Fe (Viegas *et al*. 2022). Lindolfo *et al*. (2020) studied 9-year-old açai trees, precisely on leaf 6, and found a concentration of 153 $mg.kg^{-1}$ of Fe.

Mn is a nutrient with limited redistribution due to its low concentration in the phloem (Prado, 2021). It plays a vital role in metabolic processes, including respiration, photosynthesis, amino acid synthesis, acting as an enzyme cofactor, and hormone activation. As a result, manganese significantly contributes to crop yields (Millaleo et al., 2010; Rashed et al., 2021). In a study of 9.5-year-old acai trees sampled on leaf 6, the average Mn concentration found was 44.6 $mg.kg^{-1}$. Cordeiro (2011), evaluating 2-year-old plants under NPK fertilization, found an average concentration of 180 $mg.kg^{-1}$ of Mn.

Veloso *et al*. (2020) point out that there is still no recommendation for an adequate concentration of nutrients for the acai tree cultivated in the state of Pará.

Evaluation of Relative Chlorophyll Content

The main pigment related to light absorption is chlorophyll, which is essential for the photochemical phase of photosynthesis, especially Chlorophyll *a*. Understanding the level of chlorophyll in the leaves of plants has long been used to demonstrate the condition of plant health, photosynthetic capacity, physiological state and the productivity of these plants (Houborg et al., 2015; Steele et al., 2008).

Evaluation of Gas Exchange

A is a gas exchange variable that refers to the difference between how much carbon the plant is gaining (total photosynthesis) and how much it is losing (respiration and photorespiration). With regard to *E*, this is the rate of water loss from the leaves to the atmosphere, which occurs due to the increase in the concentration of water vapor inside the leaf compared to the surrounding air, as well as the greater degree of stomata opening (g_s), meaning that when they are very open, they offer less resistance to the escape of water vapor. Thus, g_s measures the capacity of a set of stomata in a given unit of leaf area to conduct water vapor, per unit of time (Hunt, 2003; Xiong & Nadal, 2020).

In general, the *A* results indicate that the organic compound was important because the plant is photosynthesizing, producing (via the Calvin cycle) phosphate triose, which is the immediate product generated in the biochemical phase of photosynthesis, which is important in the formation of various compounds in the plant (Buchanan et al., 2015; Taiz et al., 2017).

In relation to g_s and *E*, organic fertilization was fundamental since it is possible to see greater results when compared to conventional management. It is important for plants to open their stomata, in balance with water replenishment via the soil, because it is through this process that they assimilate CO_2, which is the essential gas for photosynthesis (biochemical phase), as well as in the transpiration process (because they have a strong correlation), the latter being essential for there to be tension in the plant's xylem and consequently, through a gradient of water potential, there is absorption of water (and mobile ions via mass flow) from the soil to the aerial part of the plants (Buchanan et al., 2015; Chowdhury et al., 2022; Taiz et al., 2017).

Ci refers to the concentration of CO_2 in the intercellular spaces. It can be seen that the organic compound associated with liming had a positive influence on this variable, despite the fact that CO_2 is not present in the stroma of the chloroplasts, this measure helps to compress the CO_2 that can enable the biochemical phase of photosynthesis to function, which also depends on ATP, NADPH (produced in the photochemical phase) and light for it to function fully (Buchanan et al., 2015; Taiz, 2017).

A/E refers to the plant's efficiency in using water, and this process is regulated by combining crop characteristics and genetic factors (Xia et al., 2021). With the results obtained for this variable, it can be seen that nutrient management is a fundamental factor since fertilization is not only limited to providing root growth and expanding its space for water supply, but it also makes it possible to increase the plant canopy, balance transpiration-evaporation, increasing this relationship and improving the efficiency of water use by agricultural crops (Jákli et al., 2018; Trachsel et al., 2013).

With regard to the *A/Ci*, variable, this is necessary to check the carboxylation rate of the enzyme Ribulose 1.5 Bisphosphate, Rubisco. This is important because this enzyme has two functions and can use both O_2 and CO_2 in its reaction. In other words, carboxylation (when the enzyme works using CO_2 refers to the production of two molecules of 3-phosphoglycerate which will be reduced to phosphate triose (important for the formation of many compounds in the plant) in the Calvin cycle (Buchanan *et al*., 2015; Taiz, 2017). That is, organic fertilization was fundamental to the results obtained.

In general, the lowest results observed for these physiological variables may be associated with oxidative stress caused by inadequate nutrient supply (Pereira et al., 2015).

Correlation and PCA

With regard to potassium, this element exhibited a significant correlation with SC, circumference at breast height, NL, and calcium levels. Calcium, in turn, showed a significant correlation with potassium, magnesium, manganese, and the assimilation-to-internal CO_2 ratio, with a negative correlation. Magnesium was significantly correlated with calcium, iron, sulfur (negative correlation), transpiration rate (negative correlation), and assimilation-to-internal (negative correlation). Sulfur, in turn, exhibited a significant negative correlation with magnesium (Figure 4).

For micronutrients, boron was significantly correlated with phosphorus. Iron showed significant correlations with magnesium, manganese, and instantaneous water use efficiency, while also exhibiting a negative correlation with transpiration rate. Manganese was significantly correlated with calcium and iron (Figure 4).

Relative chlorophyll content (SPAD index) was significantly correlated with SC, circumference at breast height, and NL (Figure 4). Regarding the gas exchange variables, Net CO2 assimilation exhibited a significant correlation with transpiration rate, stomatal conductance, and assimilation-to-internal CO_2 ratio. Similarly, the transpiration rate was significantly correlated with Net CO_2 assimilation, stomatal conductance, magnesium levels (negative correlation), iron levels (negative correlation), and instantaneous water use efficiency (negative correlation). The stomatal conductance variable showed significant correlations with Net CO_2 assimilation, transpiration rate, and instantaneous water use efficiency (negative correlation) (Figure 4).

With respect to intercellular CO_2 concentration, this variable exhibited a significant negative correlation with the assimilation-to-internal CO_2 ratio. The instantaneous water use efficiency variable was significantly correlated with iron levels while showing negative correlations with transpiration rate and stomatal conductance. Finally, the assimilation-to-internal CO_2 ratio demonstrated significant correlations with Net CO_2 assimilation while being negatively correlated with calcium, magnesium, and intercellular CO_2 concentration (Figure 4).

The second principal component (Dim 2) accounted for 20.33% of the data variability. This component was mainly influenced by SC, transpiration rate, and stomatal conductance, which had the greatest positive effects. Meanwhile, nitrogen, relative chlorophyll content (SPAD index), Net CO_2 assimilation, and intercellular CO_2 concentration had the smallest positive effects. On the other hand, magnesium and iron had the greatest negative effects, while instantaneous water use efficiency and manganese had the smallest negative effects (Figure 5).

In addition, all the liming treatments, with the exception of treatment 1, had a strong influence on all the biometric and nutritional variables (with the exception of N and S) and on the relative chlorophyll content and intercellular CO_2 concentration. There was also a strong influence of the treatments without liming on the nutritional variables nitrogen and sulfur, as well as on the gas exchange variables Net CO_2 Assimilation, transpiration rate, stomatal conductance, and assimilation-to-internal CO_2 ratio. However, treatments 8 and 14 were exceptions to this trend.

Conclusions

This research showed that the reuse of agro-industrial waste, in the form of organic compost, especially at doses of 8 and 10 kg, together with the use of corrective practices (liming) improved soil fertility and favored growth, with SH of 3.6 m, SC of 68.22 cm, SBH of 21.84 cm, and an average of nine leaves.

In addition, the mineral nutrition of the *Euterpe oleracea* plants was favored, with macro and micronutrient contents in the following descending order: N>S>Ca>K>P>Mg; B>Mn>Fe. They also favored the relative chlorophyll content with an average value of 107.97 SPAD units, as well as providing good results for *A*, *gs*, *E*, *Ci*, *A/E*, *A/Ci*.

These results were explained by the supply of essential nutrients that enabled greater growth, positively influencing the nutritional content of the plant tissue and the photosynthetic machinery.

Therefore, this study provided information that contributes to an alternative low-cost and sustainable production of *Euterpe oleracea* plants under organic production in the Amazon.

References

Adetunji, A. T., Ncube, B., Mulidzi, R., & Lewu, F. B. (2020). Management impact and benefit of cover crops on soil quality: A review. *Soil and Tillage Research*, *204*(June), 104717. https://doi.org/10.1016/j.still.2020.104717

Al-Suhaibani, N., Selim, M., Alderfasi, A., El-Hendawy, S., & Selim, M. (2020). Comparative performance of integrated nutrient management between composted agricultural wastes, chemical fertilizers, and biofertilizers in improving soil quantitative and qualitative properties and crop yields under arid conditions. *Agronomy*, *10*(10), 1–25. https://doi.org/10.3390/agronomy10101503

Almeida, U. O., Andrade Neto, R. de C., Lunz, A. M. P., Costa, D. A., Araujo, J. M., & Rodrigues, M. J. da S. (2018). Crescimento de açaizeiro (Euterpe precatoria Mart.) consorciado com bananeira. *South American Journal of Basic Education, Technical and Technological*, *5*(3), 1–13. https://periodicos.ufac.br/index.php/SAJEBTT/article/view/2177/1345

Araújo, F. R., Viégas, I., Silva, D. A. S., Galvão, J. R., Rodriguez, D. M., Silva Júnior, M. L., & Campos, P. D. S. (2019). Nutrient omission effects on growth and nutritional status of seedlings of assai palm (Euterpe oleracea Mart.) var. Pai d'égua in clayey Oxisol. *Journal of Agricultural Science (Toronto)*, *11*(6), 510–518. https://doi.org/https://doi.org/10.5539/jas.v11n6p510

Auliyani, D., & Wahyuningrum, N. (2021). Rainfall variability based on the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) in Lesti watershed, Java Island, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *874*(1). https://doi.org/10.1088/1755-1315/874/1/012003

Bai, Z., Caspari, T., Gonzalez, M. R., Batjes, N. H., Mäder, P., Bünemann, E. K., de Goede, R., Brussaard, L., Xu, M., Ferreira, C. S. S., Reintam, E., Fan, H., Mihelič, R., Glavan, M., & Tóth, Z. (2018). Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agriculture, Ecosystems and Environment*, *265*(May), 1–7. https://doi.org/10.1016/j.agee.2018.05.028

Bang, T. C., Husted, S., Laursen, K. H., Persson, D. P., & Schjoerring, J. K. (2021). The molecular–physiological functions of mineral macronutrients and their consequences for deficiency symptoms in plants. *New Phytologist*, *229*(5), 2446–2469. https://doi.org/10.1111/nph.17074

Barros, L. S., Silva, E. R. R., Maciel, M. de N. M., Melo, V. S., Cicerelli, R. E., & Almeida, T. de. (2022). Spatial Dispersion of Chemical Attributes of the Soil of an Açaí Tree in the Amazon Region. *Anuario Do Instituto de Geociencias*, *45*, 1–10. https://doi.org/10.11137/1982-3908_2022_45_40848

Bezerra, J. L. de S., Andrade Neto, R. de C., Lunz, A. M. P., Araújo, C. S. de, & Almeida, U. O. de. (2018). FONTES E DOSES DE NITROGÊNIO NA PRODUÇÃO DE MUDAS DE AÇAIZEIRO (Euterpe oleracea Mart). *Enciclopédia Biosfera*, *15*(October 2019), 530–543. https://doi.org/10.18677/EnciBio

Bokor, B., Santos, C. S., Kostoláni, D., Machado, J., da Silva, M. N., Carvalho, S. M. P., Vaculík, M., & Vasconcelos, M. W. (2021). Mitigation of climate change and environmental hazards in plants: Potential role of the beneficial metalloid silicon. *Journal of Hazardous Materials*, *416*(May). https://doi.org/10.1016/j.jhazmat.2021.126193

Brady, N. C., & Weil, R. R. (2010). Elements of the Nature and Properties of Soils. In *Journal of Chemical Information and Modeling* (Vol. 53, Issue 9).

Brasil. (2020). Instrução Normativa Nº 61, de 8 de julho de 2020. *Instrução Normativa Nº 61, de 8 de Julho de 2020*, 1–15. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/fertilizantes/legislacao/in-61-de-8-7-2020-organicos-e-biofertilizantes-dou-15-7-20.pdf

Brasil, E. C., Nascimento, E. V. S., & Alencar Sobrinho, R. J. (2009). Macronutrientes em diferentes partes de indivíduos de açaizeiro (Euterpe oleracea mart.) provenientes de populações nativas de municípios do estado do Pará. In *Congresso Brasileiro de Ciência do Solo* (O Solo e a Produção de Bioenergia: Perspectivas e Desafios. Fortaleza: SBCS, 2009., Issue 1). https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/572574/1/2967.pdf

Brichi, L., Fernandes, J. V. M., Silva, B. M., Vizú, J. de F., Junior, J. N. G., & Cherubin, M. R. (2023). Organic residues and their impact on soil health, crop production and sustainable agriculture: A review including bibliographic analysis. *Soil Use and Management*, *39*(2), 686–706. https://doi.org/10.1111/sum.12892

Buchanan, B. B., Grissem, W., & Jones, R. L. (2015). Biochemistry and molecular biology of plants. In *Analytical Biochemistry* (John wiley, Vol. 11, Issue 1). http://link.springer.com/10.1007/978-3-319-59379-1%0Ahttp://dx.doi.org/10.1016/B978-0-12-420070-8.00002-7%0Ahttp://dx.doi.org/10.1016/j.ab.2015.03.024%0Ahttps://doi.org/10.1080/07352689.2018.1441103%0Ahttp://www.chile.bmw-motorrad.cl/sync/showroom/lam/es/

Camacho-cristóbal, J. J., Rexach, J., & González-Fontes, A. (2008). Boron in plants: Deficiency and toxicity. *Journal of Integrative Plant Biology*, *50*(10), 1247–1255. https://doi.org/10.1111/j.1744-7909.2008.00742.x

Campbell, A. J., Carvalheiro, L. G., Maués, M. M., Jaffé, R., Giannini, T. C., Freitas, M. A. B., Coelho, B. W. T., & Menezes, C. (2018). Anthropogenic disturbance of tropical forests threatens pollination services to açaí palm in the Amazon river delta. *Journal of Applied Ecology*, *55*(4), 1725–1736. https://doi.org/10.1111/1365-2664.13086

Campos, M., Rossato, O. B., Marasca, I., Martello, J. M., de Siqueira, G. F., Garcia, C. P., Rossetto, R., Calonego, J. C., Cantarella, H., & Crusciol, C. A. C. (2022). Deep tilling and localized liming improve soil chemical fertility and sugarcane yield in clayey soils. *Soil and Tillage Research*, *222*(June 2021). https://doi.org/10.1016/j.still.2022.105425

Chen, Z. C., Peng, W. T., Li, J., & Liao, H. (2018). Functional dissection and transport mechanism of magnesium in plants. *Seminars in Cell and Developmental Biology*, *74*, 142–152. https://doi.org/10.1016/j.semcdb.2017.08.005

Cherubin, M. R., Pinheiro Junior, C. R., Souza, L. N., Canisares, L. P., & Cerri, C. E. P. (2025). Exploring soil health research in Brazil: A critical analysis of national challenges, opportunities, and priorities. *Land Use Policy*, *157*, 107677. https://doi.org/10.1016/j.landusepol.2025.107677

Chowdhury, F. I., Arteaga, C., Alam, M. S., Alam, I., & Resco de Dios, V. (2022). Drivers of nocturnal stomatal conductance in C3 and C4 plants. *Science of the Total Environment*, *814*. https://doi.org/10.1016/j.scitotenv.2021.151952

Condé, T. M., Condé, J. D., & Lacerda Sousa, C. W. (2020). Açaí fruit production and carbon stock in managed plantations in Southeast of Roraima. *Revista Agro@Mbiente On-Line*, *14*, 1–15. https://doi.org/10.18227/1982-8470ragro.v14i0.5849

Cordeiro, R. A. M. (2011). *Crescimento e nutrição mineral do açaizeiro (Euterpe oleracea Mart.), em função da idade em sistemas agroflorestais no munícipio de Tomé-açu, Pará* [Universidade Federal Rural da Amazônia]. http://repositorio.ufra.edu.br/jspui/handle/123456789/1204

Dawson, J. J. C., & Smith, P. (2007). Carbon losses from soil and its consequences for land-use management. *Science of the Total Environment*, *382*(2–3), 165–190. https://doi.org/10.1016/j.scitotenv.2007.03.023

Deng, Z. (2017). Utilization of agricultural waste resources utilization strategy of developing agricultural. Recycling economy. *Agricultural Science and Technology*, *5*, 161–162.

Dussadee, N., & Ramaraj, R. (2023). *Integrated management of organic agricultura waste enhancing soil quality, mitigating climate change and advancing biofuel production* (Issue January). https://www.researchgate.net/profile/Rajeswaran-Ramaraj/publication/377396858_The_5_th_International_Conference_on_Renewable_Energy_Sustainable_Environmental_Agricultural_and_Artificial_Intelligence_Technologies_Integrated_management_of_organic_agricultur

EMBRAPA. (2023). *Área plantada com açaizeiros de terra firme gerados pela pesquisa cresce 675% no Brasil*. https://www.embrapa.br/en/busca-de-noticias/-/noticia/79157772/area-plantada-com-acaizeiros-de-terra-firme-gerados-pela-pesquisa-cresce-675-no-brasil

Fagan, E. B., Ono, E. O., Rodrigues, J. D., Soares, L. S., & Dourado Neto, D. (2016). *Fisiologia vegetal: metabolismo e nutrição mineral* (Andrei Editora (ed.)). 2016. https://repositorio.usp.br/item/002765918

Farias Neto, J. T. (2019). BRS Pai d'égua : cultivar de açaí para terra firme com suplementação hídrica. *Comunicado Técnico*, *317*, 8. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/204487/1/ComTec-317.pdf

Fernandes, M. S., Souza, S. R., & Santos, L. A. (2018). Nutrição mineral de plantas. In S. R. FERNANDES, M.S.; SANTOS, L.A.; SOUZA (Ed.), *Nutrição mineral de plantas* (Sociedade, pp. 125–166).

Figueiredo, A. M., Cardoso, A. C., Buzati Pereira, B. L., Candido Silva, R. A., Goncalves Della Ripa, A. F., Bachiega Pinelli, T. F., Oliveira, B. C., Murino Rafacho, B. P., Watanabe Ishikawa, L. L., Azevedo, P. S., Okoshi, K., Henrique Fernandes, A. A., Mamede Zornoff, L. A., Minicucci, M. F., Polegato, B. F., & Rupp Paiva, S. A. (2022). Açai supplementation (Euterpe oleracea Mart.) attenuates cardiac remodeling after myocardial infarction in rats through different mechanistic pathways. *PLoS ONE*, *17*(3 March), 1–17. https://doi.org/10.1371/journal.pone.0264854

Filizola, H. F., Gomes, M. A. F., & Souza, M. D. de. (2006). *Manual de Procedimentos de Coleta de Amostras em Áreas Agrícolas para Análise da Qualidade Ambiental : Solo , Água e Sedimentos Coleta de Amostras em Áreas Agrícolas para Análise da Qualidade Ambiental : Solo , Água e Sedimentos*.

Fontes, M. P. F., & Alleoni, L. R. F. (2006). Electrochemical attributes and availability of nutrients, toxic elements, and heavy metals in tropical soils. *Scientia Agricola*, *63*(6), 589–608. https://doi.org/10.1590/s0103-90162006000600014

Ganeteg, U., Ahmad, I., Jämtgård, S., Aguetoni-Cambui, C., Inselsbacher, E., Svennerstam, H., Schmidt, S., & Näsholm, T. (2017). Amino acid transporter mutants of Arabidopsis provides evidence that a non-mycorrhizal plant acquires organic nitrogen from agricultural soil. *Plant Cell and Environment*, *40*(3), 413–423. https://doi.org/10.1111/pce.12881

Gulhane, V. A., Rode, S. V., & Pande, C. B. (2023). Correlation Analysis of Soil Nutrients and Prediction Model Through ISO Cluster Unsupervised Classification with Multispectral Data. *Multimedia Tools and Applications*, *82*(2), 2165–2184. https://doi.org/10.1007/s11042-022-13276-2

Guo, W., Nazim, H., Liang, Z., & Yang, D. (2016). Magnesium deficiency in plants: An urgent problem. *Crop Journal*, *4*(2), 83–91. https://doi.org/10.1016/j.cj.2015.11.003

Han, Z., Xu, P., Li, Z., Lin, H., Zhu, C., Wang, J., & Zou, J. (2022). Microbial diversity and the abundance of keystone species drive the response of soil multifunctionality to organic substitution and biochar amendment in a tea plantation. *GCB Bioenergy*, *14*(4), 481–495. https://doi.org/10.1111/gcbb.12926

Hänsch, R., & Mendel, R. R. (2009). Physiological functions of mineral micronutrients (Cu, Zn, Mn, Fe, Ni, Mo, B, Cl). *Current Opinion in Plant Biology*, *12*(3), 259–266. https://doi.org/10.1016/j.pbi.2009.05.006

Hartemink, A. E., & Barrow, N. J. (2023). Soil pH - nutrient relationships: the diagram. *Plant and Soil*, *486*(1–2), 209–215. https://doi.org/10.1007/s11104-022-05861-z

Hawkesford, M., Horst, W., Kichey, T., Lambers, H., Schjoerring, J., MØller, I. S., & White, P. (2012). Functions of macronutrients. In: Marschner's mineral nutrition of higher plants. In P. Marschner (Ed.), *Academic press* (Third Edit, pp. 135–189). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-384905-2.00006-6

Homma, A. K. O., Nogueira, O. L., Menezes, A. J. E. A., Carvalho, J. E. U., Nicoli, C. M. L., & Matos, G. B. de. (2006). Açaí: novos desafios e tendencias. *Amazônia: Ciência & Desenvolvimento*, *1*(2), 7–23.

Hossain, M. E., Shahrukh, S., & Hossain, S. A. (2022). Chemical Fertilizers and Pesticides: Impacts on Soil Degradation, Groundwater, and Human Health in Bangladesh. *Environmental Degradation: Challenges and Strategies for Mitigation*, 63–92.

Houborg, R., Fisher, J. B., & Skidmore, A. K. (2015). Advances in remote sensing of vegetation function and traits. *International Journal of Applied Earth Observation and Geoinformation*, *43*, 1–6. https://doi.org/10.1016/j.jag.2015.06.001

Hunt, S. (2003). Measurements of photosynthesis and respiration in plants. *Physiologia Plantarum*, *117*(3), 314–325. https://doi.org/10.1034/j.1399-3054.2003.00055.x

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. (2017). *Santo Antônio do Tauá*. https://cidades.ibge.gov.br/brasil/pa/santo-antonio-dotaua/panorama

İnik, O., İnik, Ö., Öztaş, T., Demir, Y., & Yüksel, A. (2023). Prediction of Soil Organic Matter with Deep Learning. *Arabian Journal for Science and Engineering*, *48*(8), 10227–10247. https://doi.org/10.1007/s13369-022-07575-x

Jákli, B., Hauer-Jákli, M., Böttcher, F., Meyer zur Müdehorst, J., Senbayram, M., & Dittert, K. (2018). Leaf, canopy and agronomic water-use efficiency of field-grown sugar beet in response to potassium fertilization. *Journal of Agronomy and Crop Science*, *204*(1), 99–110. https://doi.org/10.1111/jac.12239

Jiang, Y., Liao, P., van Gestel, N., Sun, Y., Zeng, Y., Huang, S., Zhang, W., & van Groenigen, K. J. (2018). Lime application lowers the global warming potential of a double rice cropping system. *Geoderma*, *325*(December 2017), 1–8. https://doi.org/10.1016/j.geoderma.2018.03.034

Johnson, R., Vishwakarma, K., Hossen, M. S., Kumar, V., Shackira, A. M., Puthur, J. T., Abdi, G., Sarraf, M., & Hasanuzzaman, M. (2022). Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. *Plant Physiology and Biochemistry*, *172*(January), 56–69. https://doi.org/10.1016/j.plaphy.2022.01.001

Kohli, S. K., Kaur, H., Khanna, K., Handa, N., Bhardwaj, R., Rinklebe, J., & Ahmad, P. (2023). Boron in plants: uptake, deficiency and biological potential. *Plant Growth Regulation*, *100*(2), 267–282. https://doi.org/10.1007/s10725-022-00844-7

Kour, J., Khanna, K., Singh, A. D., Dhiman, S., Bhardwaj, T., Devi, K., Sharma, N., Ohri, P., & Bhardwaj, R. (2023). Calcium's multifaceted functions: From nutrient to secondary messenger during stress. *South African Journal of Botany*, *152*, 247–263. https://doi.org/10.1016/j.sajb.2022.11.048

Lal, R. (2020). Food security impacts of the "4 per Thousand" initiative. *Geoderma*, *374*(February), 114427. https://doi.org/10.1016/j.geoderma.2020.114427

Lepsch, I. F. (2021). *19 lições de pedologia* (A. P. Chavez, C. G. Silva, J. G. T. Tundisi, L. E. Sánchez, P. Helene, R. F. Santos, & T. G. Florenzano (eds.); 2ª Edição). Oficina de textos.

Lima, H. N., Mello, J. W. V., Schaefer, C. E. G. R., Ker, J. C. K., & Lima, M. N. (2006). Mineralogia e química de três solos de uma toposequência bacia sedimentar do Alto Solimões, Amazônia Ocidental. *Revista Brasileira de Ciência Do Solo*, *30*, 59–68.

Lindolfo, M. M., Matos, G. S. B. de, Pereira, W. V. da S., & Fernandes, A. R. (2020). Productivity and nutrition of fertigated açaí palms according to boron fertilization. *Revista Brasileira de Fruticultura*, *42*(2), 0–1. https://doi.org/10.1590/0100-29452020601

Malavolta, E. (2006). *Manual de nutrição mineral de plantas* (A. Ceres (ed.)). Ceres, Agronômica.

Malhotra, H., Vandana, S, S., & Pandey, R. (2018). Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. In *Plant Nutrients and Abiotic Stress Tolerance*. Springer. https://doi.org/https://doi.org/10.1007/978-981-10-9044-8_7

Manmai, N., Unpaprom, Y., & Ramaraj, R. (2021). Bioethanol production from sunflower stalk: application of chemical and biological pretreatments by response surface methodology (RSM). *Biomass Conversion and Biorefinery*, *11*(5), 1759–1773. https://doi.org/10.1007/s13399-020-00602-7

Matta, F. V., Xiong, J., Lila, M. A., Ward, N. I., Felipe-Sotelo, M., & Esposito, D. (2020). Chemical composition and bioactive properties of commercial and non-commercial purple and white açaí berries. *Foods*, *9*(10), 1–17. https://doi.org/10.3390/foods9101481

Millaleo, R., Reyes-Díaz, M., Ivanov, A. G., Mora, M. L., & Alberdi, M. (2010). Manganese as essential and toxic element for plants: Transport, accumulation and resistance mechanisms. *Journal of Soil Science and Plant Nutrition*, *10*(4), 476–494. https://doi.org/10.4067/s0718-95162010000200008

Miyazawa, M., Pavan, M. A., Muraoka, T., Carmo, C. A. F. S., & Melo, W. J. (2009). Análise química de tecido vegetal. In *Manual de análises químicas de solos, plantas e fertilizantes* (Embrapa In). Embrapa Solos.

Möller, K., & Schultheiß, U. (2015). Chemical characterization of commercial organic fertilizers. *Archives of Agronomy and Soil Science*, *61*(7), 989–1012. https://doi.org/10.1080/03650340.2014.978763

Moreira, A., & Fageria, N. K. (2009). Soil chemical attributes of Amazonas State, Brazil. *Communications in Soil Science and Plant Analysis*, *40*(17–18), 2912–2925. https://doi.org/10.1080/00103620903175371

Myers, S. S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., Dangour, A. D., & Huybers, P. (2017). Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition. *Annual Review of Public Health*, *38*, 259–277.

https://doi.org/10.1146/annurev-publhealth-031816-044356

Nandal, V., & Solanki, M. (2021). Zn As a Vital Micronutrient in Plants. *Journal of Microbiology, Biotechnology and Food Sciences*, *11*(3), 1–9. https://doi.org/10.15414/JMBFS.4026

Narayan, O. P., Kumar, P., Yadav, B., Dua, M., & Johri, A. K. (2023). Sulfur nutrition and its role in plant growth and development. *Plant Signaling and Behavior*, *18*(1). https://doi.org/10.1080/15592324.2022.2030082

Nogueira, O. L., & Da Conceiçao, H. E. O. (2000). Growth analysis of açaí palm trees (Euterpe oleracea Mart.) in floodplain of Amazon estuary. *Pesquisa Agropecuaria Brasileira*, *35*(11), 2167–2173. https://doi.org/10.1590/s0100-204x2000001100007

Obey, G., Adelaide, M., & Ramaraj, R. (2022). Biochar derived from non-customized matamba fruit shell as an adsorbent for wastewater treatment. *Journal of Bioresources and Bioproducts*, *7*(2), 109–115. https://doi.org/10.1016/j.jobab.2021.12.001

Oliveira, M., CArvalho, J. E. U., Nascimento, W. M. O., & Muller, C. H. (2002). *Cultivo do Açaizeiro para Produção de Frutos 26*. EMBRAPA. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/405768/cultivo-do-acaizeiro-para-producao-de-frutos

Oliveira, M., Farias Neto, J. T., Mattietto, R. D. A., Mochiutti, S., & Carvalho, A. (2017). Açaí: Euterpe oleracea. In *Instituto Interamericano de Cooperación para la Agricultura/PROCISUR*.

Oliveira, M. S. P. (2005). *Caracterização molecular e morfo-agronômica de germoplasma de açaizeiro*. Universidade Federal de Lavras.

Parada, M. P., Osseweijer, P., & Duque, J. A. P. (2017). Sustainable biorefineries, an analysis of practices for incorporating sustainability in biorefinery design. *Industrial Crops and Products*, *106*, 105–123. https://doi.org/10.1016/j.indcrop.2016.08.052

Pavinato, P. S., Cherubin, M. R., Soltangheisi, A., Rocha, G. C., Chadwick, D. R., & Jones, D. L. (2020). Revealing soil legacy phosphorus to promote sustainable agriculture in Brazil. *Scientific Reports*, *10*(1), 15615. https://doi.org/10.1038/s41598-020-72302-1

Penn, C. J., & Camberato, J. J. (2019). A critical review on soil chemical processes that control how soil ph affects phosphorus availability to plants. *Agriculture (Switzerland)*, *9*(6), 1–18. https://doi.org/10.3390/agriculture9060120

Pereira, E. S., Silva, O. N., Filho, A. P., Felipe, J. P., Alves, G. A. R., & Lobato, A. K. S. (2015). Antioxidant enzymes efficiently control leaf and root cell damage in young Euterpe oleracea plants exposed to waterlogging. *Indian Journal of Plant Physiology*, *20*(3), 213–219. https://doi.org/10.1007/s40502-015-0162-7

Pereira, T. S., Lobato, A. K. S., Alves, G. A. R., Ferreira, R. N., Silva, O. N., Martins Filho, A. P., Pereira, E. S., & Sampaio, L. S. (2014). Tolerance to waterlogging in young Euterpe oleracea plants. *Photosynthetica*, *52*(2), 186–192. https://doi.org/10.1007/s11099-014-0021-1

Prado, R. . (2021a). *Mineral nutrition of tropical plants*. Springer Publishing.

Prado, R. M. (2021b). *Nutrição de plantas*.

Quesada, C. A., Lloyd, J., Anderson, L. O., Fyllas, N. M., Schwarz, M., & Czimczik, C. I. (2011). Soils of Amazonia with particular reference to the RAINFOR sites. *Biogeosciences*, *8*(6), 1415–1440. https://doi.org/10.5194/bg-8-1415-2011

Raij, B. v. (2011). Fertilidade do solo e manejo de nutrientes. In *International Plant Nutrition Institute* (p. 420).

Rashed, M., Hoque, T., Jahangir, M., & Hashem, M. (2021). Manganese as a Micronutrient in Agriculture: Crop Requirement and Management. *Journal of Environmental Science and Natural Resources*, *12*(1–2), 225–242. https://doi.org/10.3329/jesnr.v12i1-2.52040

RIBEIRO, F. O. (2017). *ESTADO NUTRICIONAL E PRODUTIVIDADE DE AÇAIZEIRO FERTIRRIGADO EM FUNÇÃO DA VARIABILIDADE ESPACIAL* (Issue 0) [Universidade Federal Rural da amazônia]. http://www.repositorio.ufra.edu.br:8080/jspui/bitstream/123456789/783/1/ESTADO NUTRICIONAL E PRODUTIVIDADE DE AÇAIZEIRO FERTIRRIGADO.pdf

Ribeiro, F. O., Fernandes, A. R., Galvão, J. R., de Matos, G. S. B., Lindolfo, M. M., dos Santos, C. R. C., & Pacheco, M. J. B. (2020). DRIS and geostatistics indices for nutritional diagnosis and enhanced yield of fertirrigated acai palm. *Journal of Plant Nutrition*, *43*(12), 1875–1886. https://doi.org/10.1080/01904167.2020.1750643

Rout, G. R., & Sahoo, S. (2015). Role of Iron in Plant Growth and Metabolism. *Reviews in*

Agricultural Science, *3*(0), 1–24. https://doi.org/10.7831/ras.3.1

Saldanha, E. C. ., Silva Junior, M. L. ., Lins, P., Pontes, M., Farias, S. C. ., & Wadt, P. G. . (2017). NUTRITIONAL DIAGNOSIS IN HYBRID COCONUT CULTIVATED IN NORTHEASTERN BRAZIL THROUGH DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS). *Revista Brasileira de Fruticultura*, *39*(1). https://doi.org/http://dx.doi.org/10.1590/0100-29452017728

Santana, A. C. (2020). *Bioeconomia aplicada ao agronegócio: mercado, externalidades e ativos naturais*.

Sardans, J., & Peñuelas, J. (2021). Potassium control of plant functions: Ecological and agricultural implications. In *Plants* (Vol. 10, Issue 2). https://doi.org/10.3390/plants10020419

Sena, I. S., Ferreira, A. M., Marinho, V. H., e Holanda, F. H., Borges, S. F., de Souza, A. A., de Carvalho R. Koga, R., Lima, A. L., Florentino, A. C., & Ferreira, I. M. (2022). Euterpe oleracea Mart (Açaizeiro) from the Brazilian Amazon: A Novel Font of Fungi for Lipase Production. *Microorganisms*, *10*(12), 1–13. https://doi.org/10.3390/microorganisms10122394

Silva, A. C. D., Smiderle, O. J., Oliveira, J. M. F. De, & Jesus, T. De. (2017). Tamanho da semente e substratos na produção de mudas de açaí. *Advances in Forestry Science*, *4*(4), 151–156.

Silva, T. R., Matos, P. R., Tambara Júnior, L. U. D., Marvila, M. T., & de Azevedo, A. R. G. (2023). A review on the performance of açaí fiber in cementitious composites: Characteristics and application challenges. *Journal of Building Engineering*, *71*(February), 106481. https://doi.org/10.1016/j.jobe.2023.106481

Silveira, R., de Mello, T. de R. B., Silva, M. R. S. S., Krüger, R. H., & Bustamante, M. M. da C. (2021). Long-term liming promotes drastic changes in the composition of the microbial community in a tropical savanna soil. *Biology and Fertility of Soils*, *57*(1), 31–46. https://doi.org/10.1007/s00374-020-01504-6

Steele, M. R., Gitelson, A. A., & Rundquist, D. C. (2008). A Comparison of Two Techniques for Nondestructive Measurement of Chlorophyll Content in Grapevine Leaves. *Agronomy Journal*, *100*(3), 779–782. https://doi.org/10.2134/agronj2007.0254N

Taiz, L., Zeiger, E., Moller, I. max, & Murphy, A. (2017). Fisiologia e Desenvolvimento Vegetal. In *Porto Alegre: Artmed: Vol. 6 ed.*

Tavares, G. S., Homma, A. K. O., Menezes, A. A., & Palheta, M. P. (2022). *Análise da produção e comercialização de açaí no estado do Pará*. https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1143144/1/LV-Sinergias-446-465.pdf

Tavares, R. F. de M. (2017). *Crescimento E Fisiologia De Mudas De Açaí E Juçara Cultivadas Sob Estresse Hídrico*.

Teixeira, P. C., Donagemma, G. K., Fontana, A., & Teixeira, W. G. (2017). *Manual de métodos de análise de solo* (3rd ed.). http://www.cse.edu.uy/sites/www.cse.edu.uy/files/documentos/Liccom_Camejo_2011-07-28.pdf

Tian, X. Y., He, D. D., Bai, S., Zeng, W. Z., Wang, Z., Wang, M., Wu, L. Q., & Chen, Z. C. (2021). Physiological and molecular advances in magnesium nutrition of plants. *Plant and Soil*, *468*(1–2), 1–17. https://doi.org/10.1007/s11104-021-05139-w

Trachsel, S., Kaeppler, S. M., Brown, K. M., & Lynch, J. P. (2013). Maize root growth angles become steeper under low N conditions. *Field Crops Research*, *140*, 18–31. https://doi.org/10.1016/j.fcr.2012.09.010

Vazquez, E., Benito, M., Espejo, R., & Teutscherova, N. (2019). Effects of no-tillage and liming amendment combination on soil carbon and nitrogen mineralization. *European Journal of Soil Biology*, *93*(April), 103090. https://doi.org/10.1016/j.ejsobi.2019.103090

Viegas, I. de J. M., Meirelles, R. de O., Frazão, D. A. C., & Conceição, H. E. O. da. (2009). Avaliação da fertilidade de um latossolo amarelo textura média para o cultivo do açaizeiro no Estado do Pará. *Revista de Ciências Agrárias Amazonian Journal of Agricultural and Environmental Sciences*, *52*(1), 23–36.

Viégas, I. de J. M., Muller, A. A., Costa, M. G., Ferreira, E. V. de O., Pinheiro, D. P., & Campos, P. S. da S. (2022). Determination of the standard leaf for nutritional diagnosis of assai palm plants. *Revista Brasileira de Fruticultura*, *44*(3), 1–14. https://doi.org/10.1590/0100-29452022078

Wu, J., Sha, C., Wang, M., Ye, C., Li, P., & Huang, S. (2021). Effect of organic fertilizer on soil bacteria in maize fields. *Land*, *10*(3), 1–14. https://doi.org/10.3390/land10030328

Xia, W., Liu, X., Xin, H., Wu, X., Liu, R., Li, J., & Zhu, J. (2021). Saussurea involucrata PIP2;7 improves photosynthesis and drought resistance by decreasing the stomatal density and increasing intracellular osmotic pressure. *Environmental and Experimental Botany*, *191*(May), 104605. https://doi.org/10.1016/j.envexpbot.2021.104605

Ximenes, L. C., Gama, J. R. V., Bezerra, T. G., & Cruz, G. da S. (2020). Importância do açaí na renda mensal da comunidade quilombola Murumuru em Santarém, Pará. *Revista Ibero-Americana de Ciências Ambientais*, *11*(2), 36–42. https://doi.org/10.6008/cbpc2179-6858.2020.002.0004

Xiong, D., & Nadal, M. (2020). Linking water relations and hydraulics with photosynthesis. *Plant Journal*, *101*(4), 800–815. https://doi.org/10.1111/tpj.14595

Yang, K., Zhu, L., Zhao, Y., Wei, Z., Chen, X., Yao, C., Meng, Q., & Zhao, R. (2019). A novel method for removing heavy metals from composting system: The combination of functional bacteria and adsorbent materials. *Bioresource Technology*, *293*(July), 122095. https://doi.org/10.1016/j.biortech.2019.122095

Yu, H., Zhao, Y., Zhang, C., Wei, D., Wu, J., Zhao, X., Hao, J., & Wei, Z. (2019). Driving effects of minerals on humic acid formation during chicken manure composting: Emphasis on the carrier role of bacterial community. *Bioresource Technology*, *294*(September), 122239. https://doi.org/10.1016/j.biortech.2019.122239

Zenda, T., Liu, S., Dong, A., & Duan, H. (2021). Revisiting Sulphur—The Once Neglected Nutrient: It's Roles in Plant Growth, Metabolism, Stress Tolerance and Crop Production. *Plants*, *9*(6), 765.

Zhang, H. Q., Zhao, X. Q., Chen, Y. L., Wang, J. L., & Shen, R. F. (2020). Improved root growth by liming aluminum-sensitive rice cultivar or cultivating an aluminum-tolerant one does not enhance fertilizer nitrogen recovery efficiency in an acid paddy soil. *Plants*, *9*(6), 1–14. https://doi.org/10.3390/plants9060765

Zhang, X., Zhang, D., Sun, W., & Wang, T. (2019). The adaptive mechanism of plants to iron deficiency via iron uptake, transport, and homeostasis. *International Journal of Molecular Sciences*, *20*(10). https://doi.org/10.3390/ijms20102424

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- HighlightsValdeci.docx